ZCO-56: Improving Coating Weight Efficiency

S. Alibeigi[1], D.A. Finnerty[1], A. Ritcey[1], A. Yahyae[1], J.R. McDermid[1], S. Ziada[1] and A.N. Hrymak[2]

[1]Dept. of Mechanical Engineering, McMaster University, Hamilton, Canada
[2]Dept of Chemical Engineering, University of Western Ontario, London, Canada

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Western

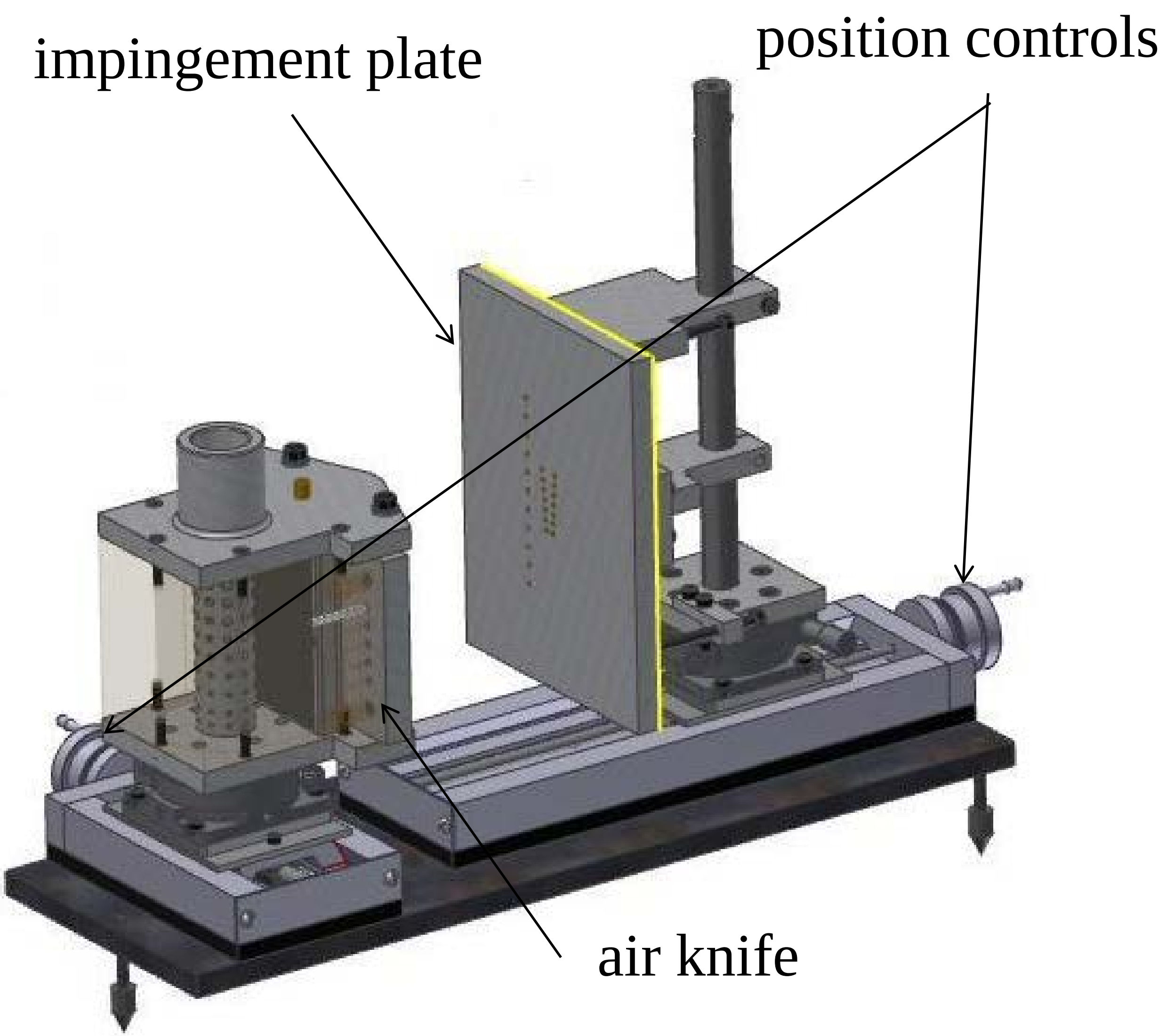
ZCO-56: Program Objectives

- **To enable improvements in coating control equipment for hot dip galvanized sheet in the two high priority areas:**
  - **improvement of accuracy and reliability of coating thickness outcomes (robust coating weight control)**
  - **extending the capabilities of this equipment to produce thinner coatings at higher line speeds than currently possible.**
- **Expected project tasks to be fulfilled (revised):**
  - **continued extension of previous ZCO-56 work on novel coating weight control designs**
  - **extension of work to Zn-Al-Mg coatings**
  - **link air knife operation to dross generation for ZCO-55**

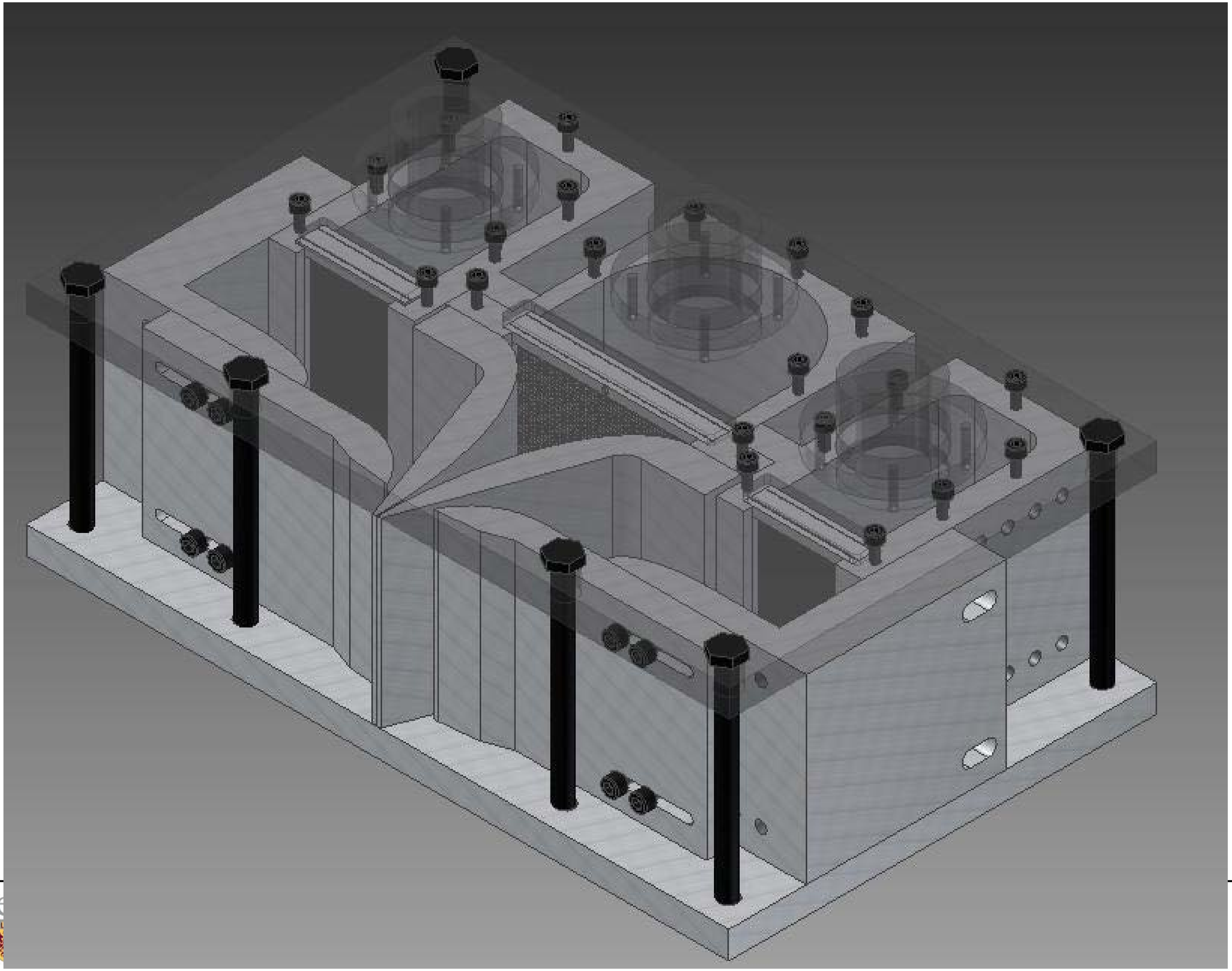
ZCO-56: Current Status (Leveraged Project)

- **NSERC CRD with ArcelorMittal Dofasco:**
  - **Task 1: Design and testing of single and multi-slot air knives (MASc Alibeigi – completed)**
  - **Task 2: Parametric study of single and multi-slot air knives (MASc Ritcey – in progress, but currently focused on shear stress measurements)**
  - **Task 3: Development of a CFD design tool for future process optimization (MASc Yahee – in progress)**
  - **Task 4: Full scale testing at the facility of industrial partner (Alibeigi – in progress)**
  - **Task 5: Fundamental understanding of unsteady flow effects on coating quality and noise generation (PhD Finnerty – in progress)**

Experimental Apparatus – Measurement System



Multi-Slot Air Knives – Isometric View



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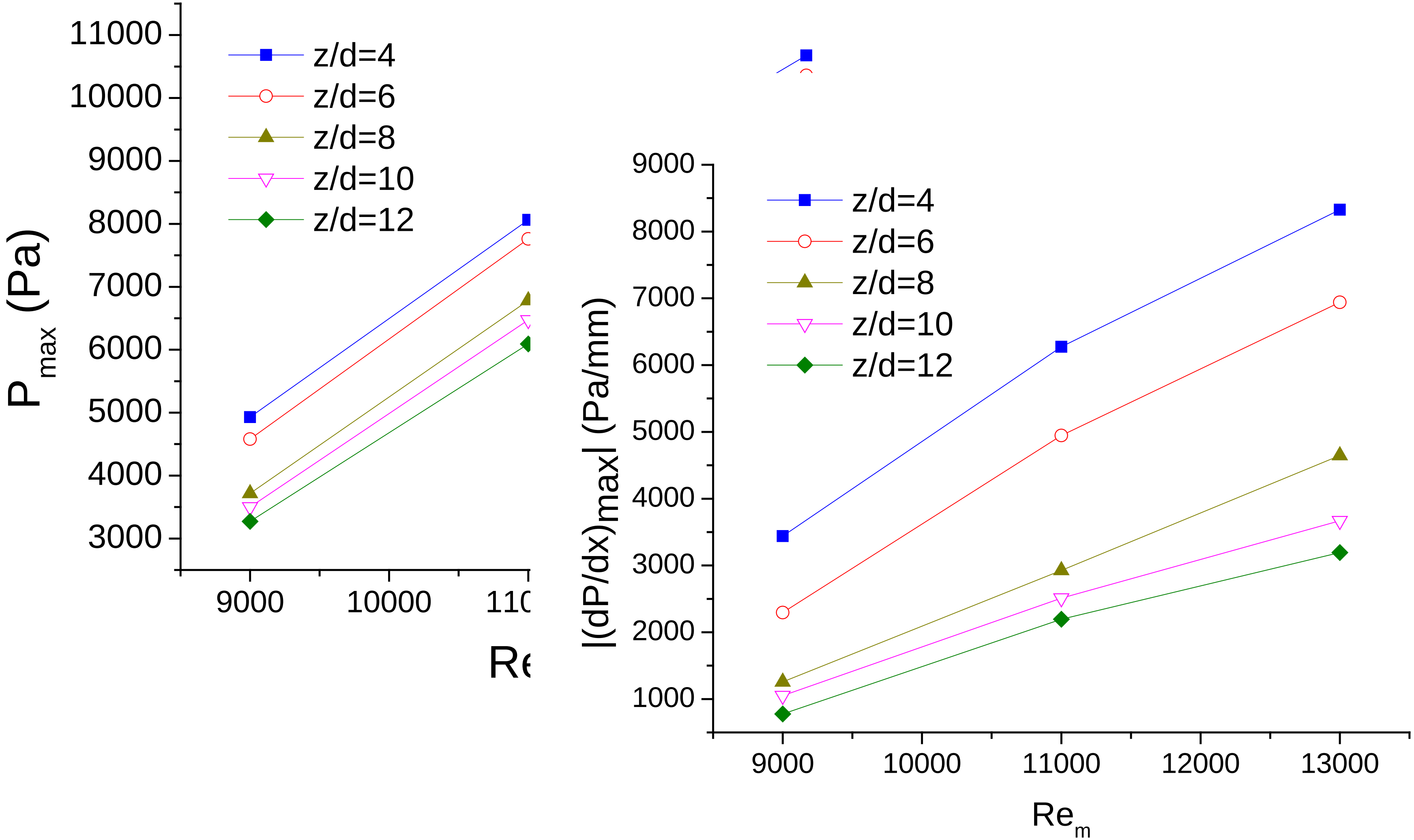
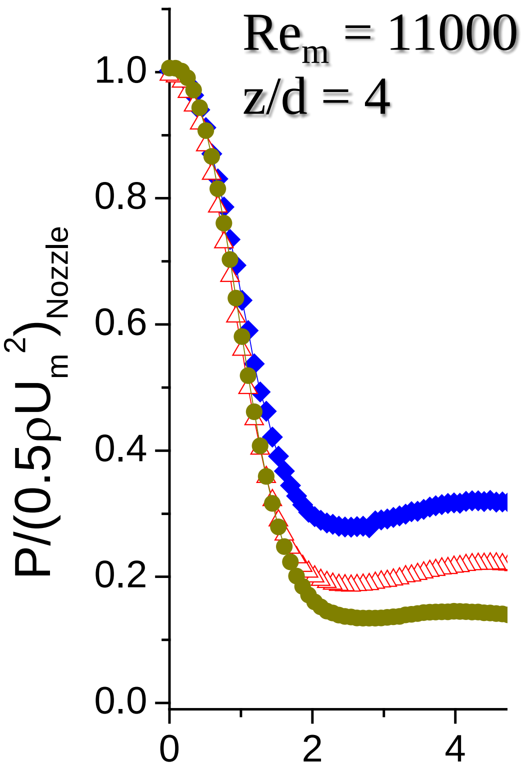
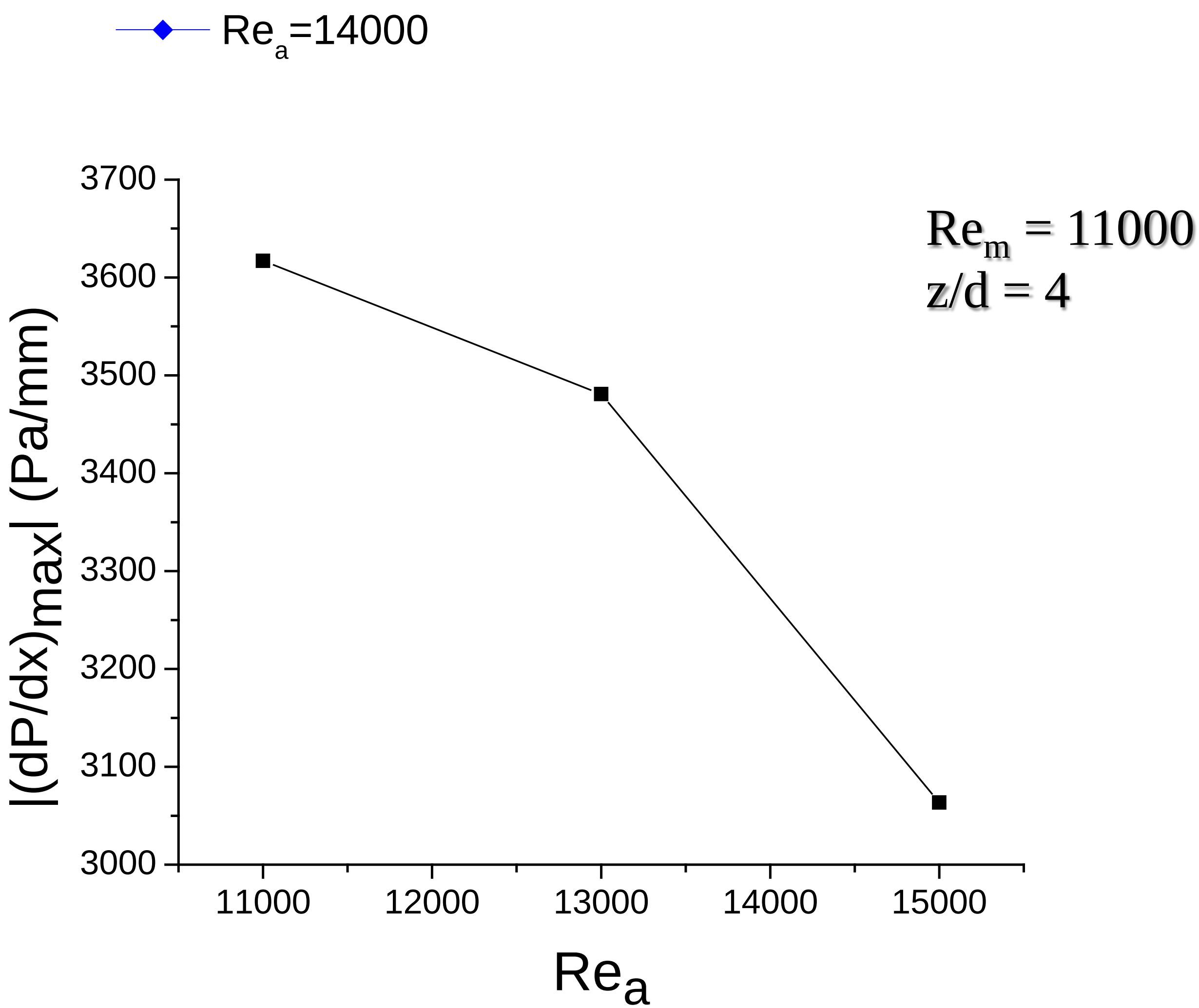
Multiple-Slot Jet – Effect of Re_m (Re_a = 11000)

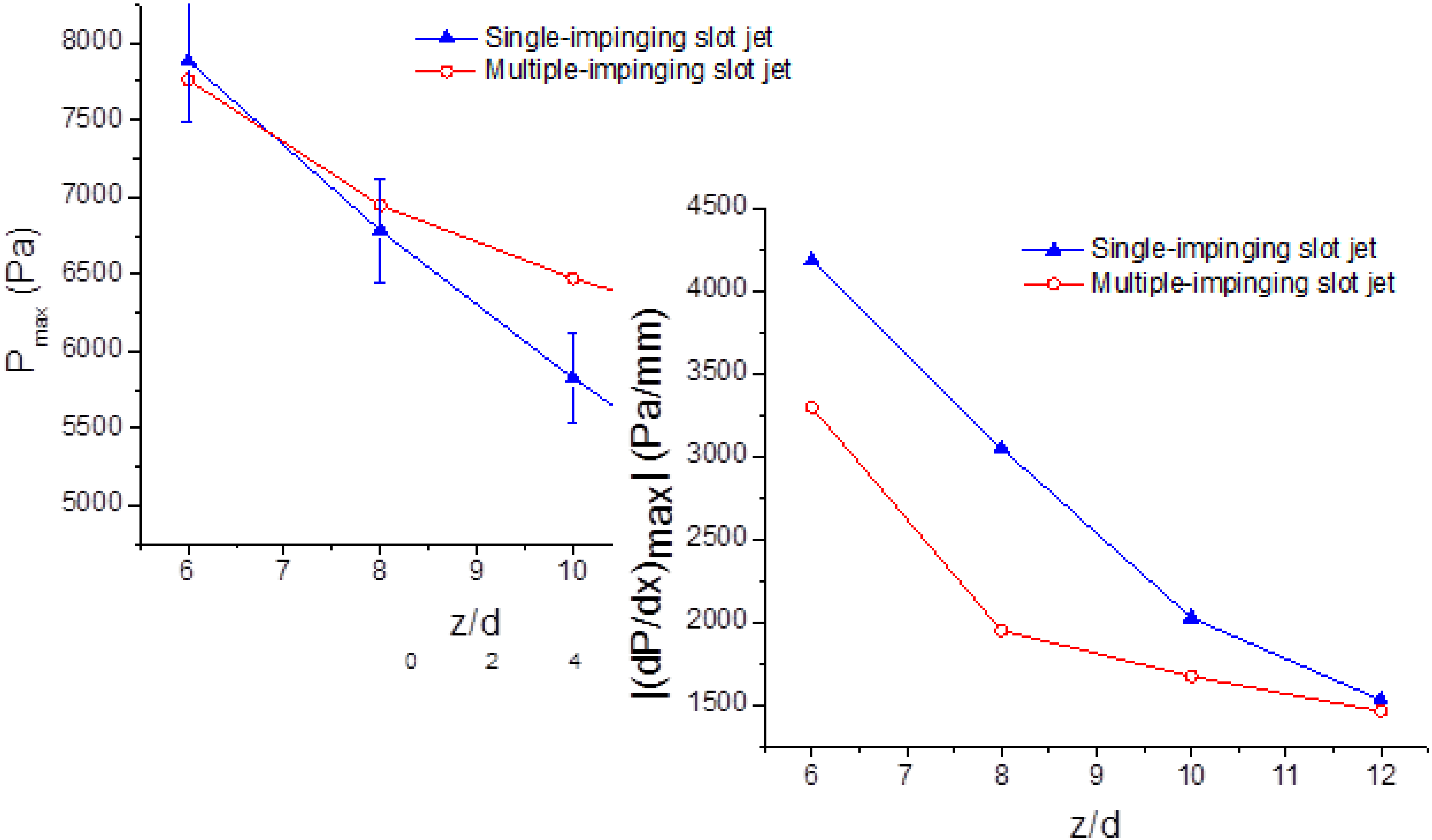


Multiple-Slot Jet – Effect of Re_a

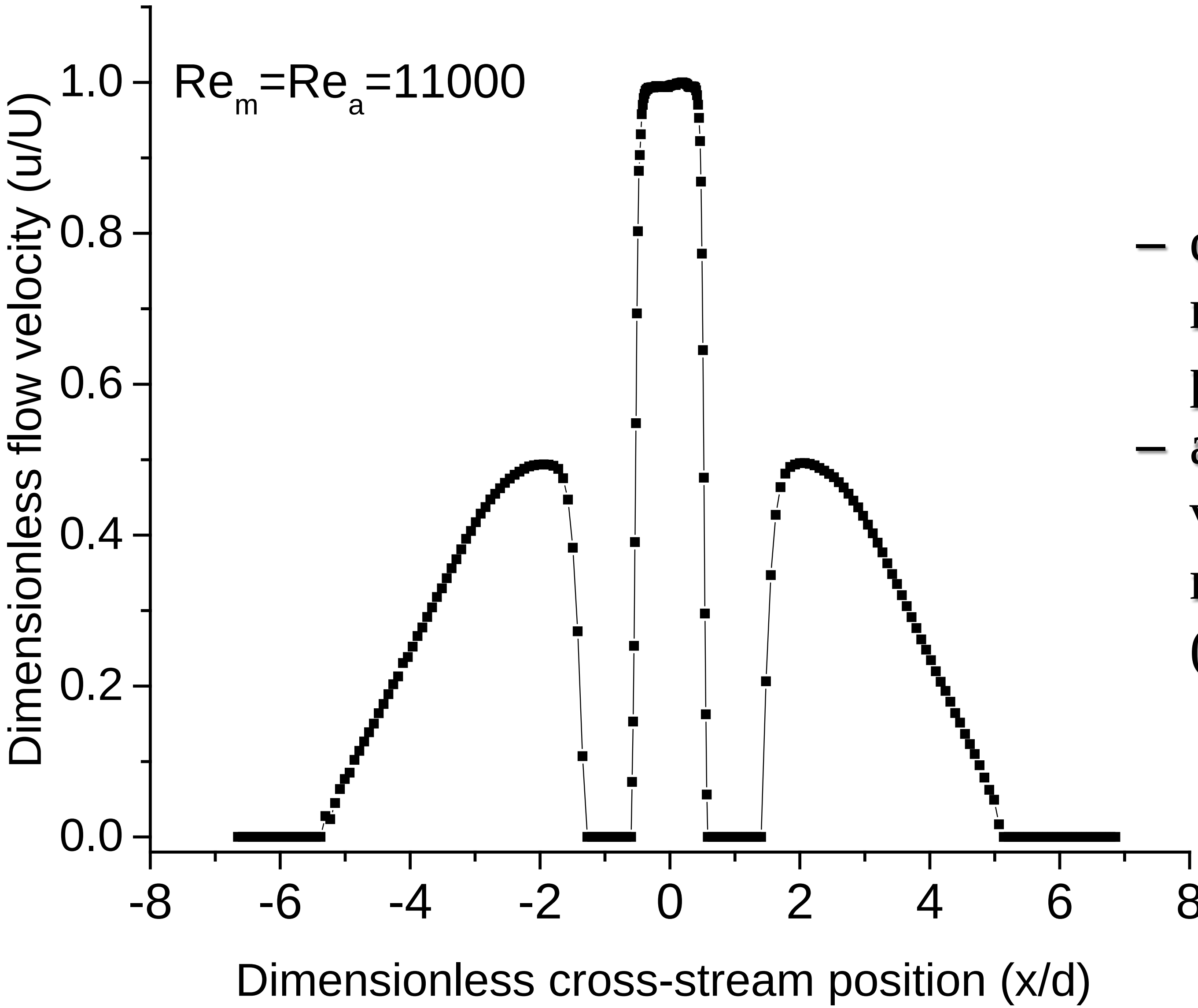




Single vs. Multiple Jet ($Re_m = Re_a = 11000$)



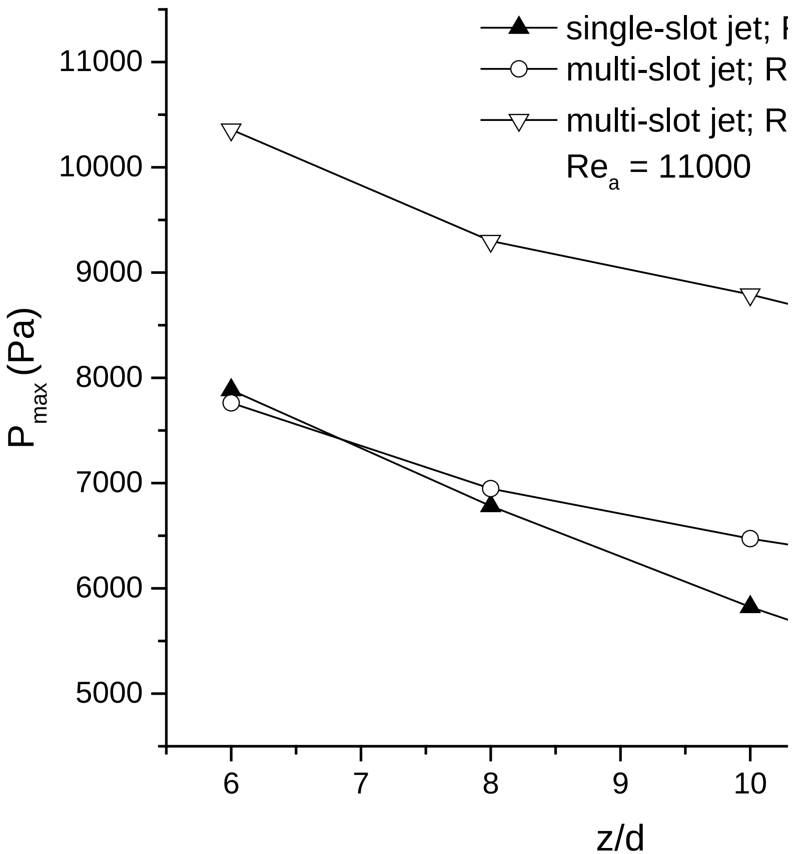
Results - Jet Velocity Profiles

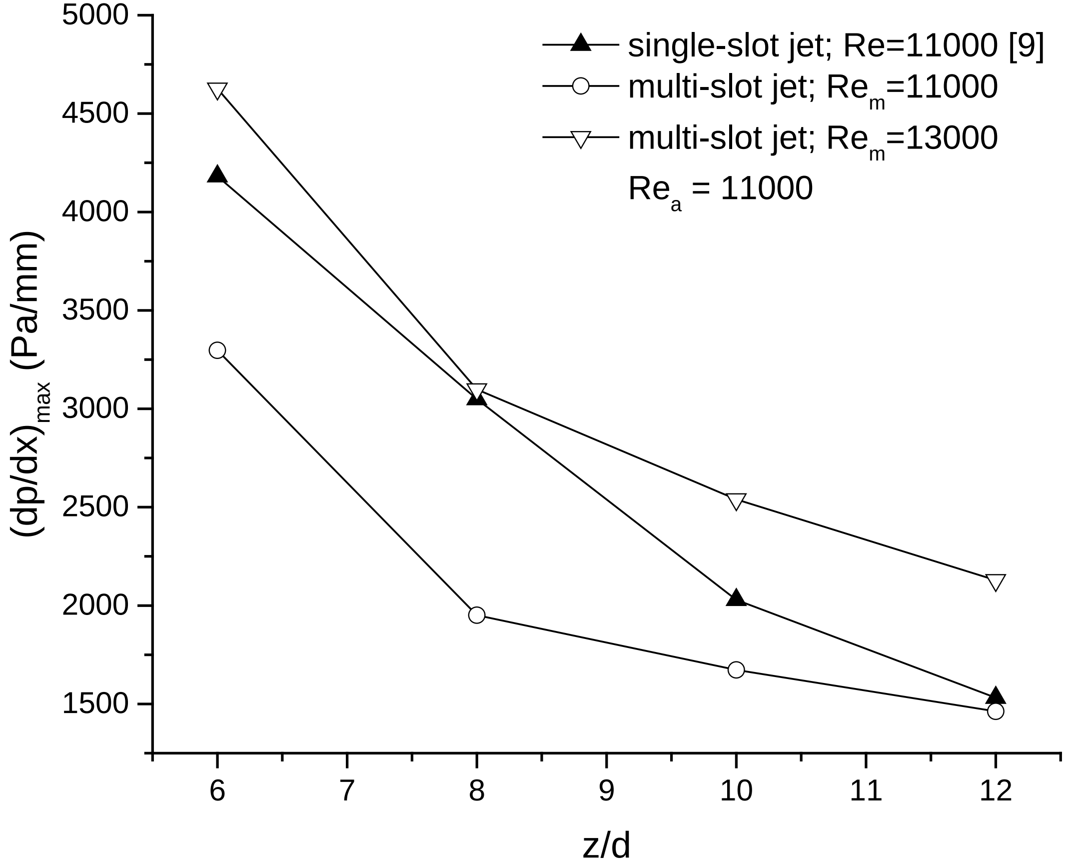


– desired "top-hat" main jet velocity profile
– auxiliary jet velocity is half main jet velocity (due to $a = 2d$)

Effect of Rem = 13000 on P_{max} and $(dp/dx)_{max}$

- a modest (2.5kPa, 0.4psi) increase in plenum pressure is able compensate for the slightly attenuated maximum pressure and $(dp/dx)_{max}$
- decreased sensitivity $(dp/dx)_{max}$ of maintained for $z/d > 8$





Re=11000 (P_{Plenum}= 7.91 kPa); Re=13000 (P_{Plenum}= 10.5 kPa)

Some Thoughts on Improving Future CFD

- **Geometry – this is the first thing to look at, making sure that the geometries do not contain a long parallel section**
  - **smaller boundary layer, reduced friction**
- **Use of the k-ε model – is the turbulent dissipation sufficiently accounted for? Worth looking into ….**
  - **alternative wall functions may also be considered**
- **Are the errors/differences significant in terms of coating predictions? Error analysis …..**
  - **Elsaadawy et. al [2007] used k-ε and had good predictions for ctg. wt. ≤ 120 g/m^2**

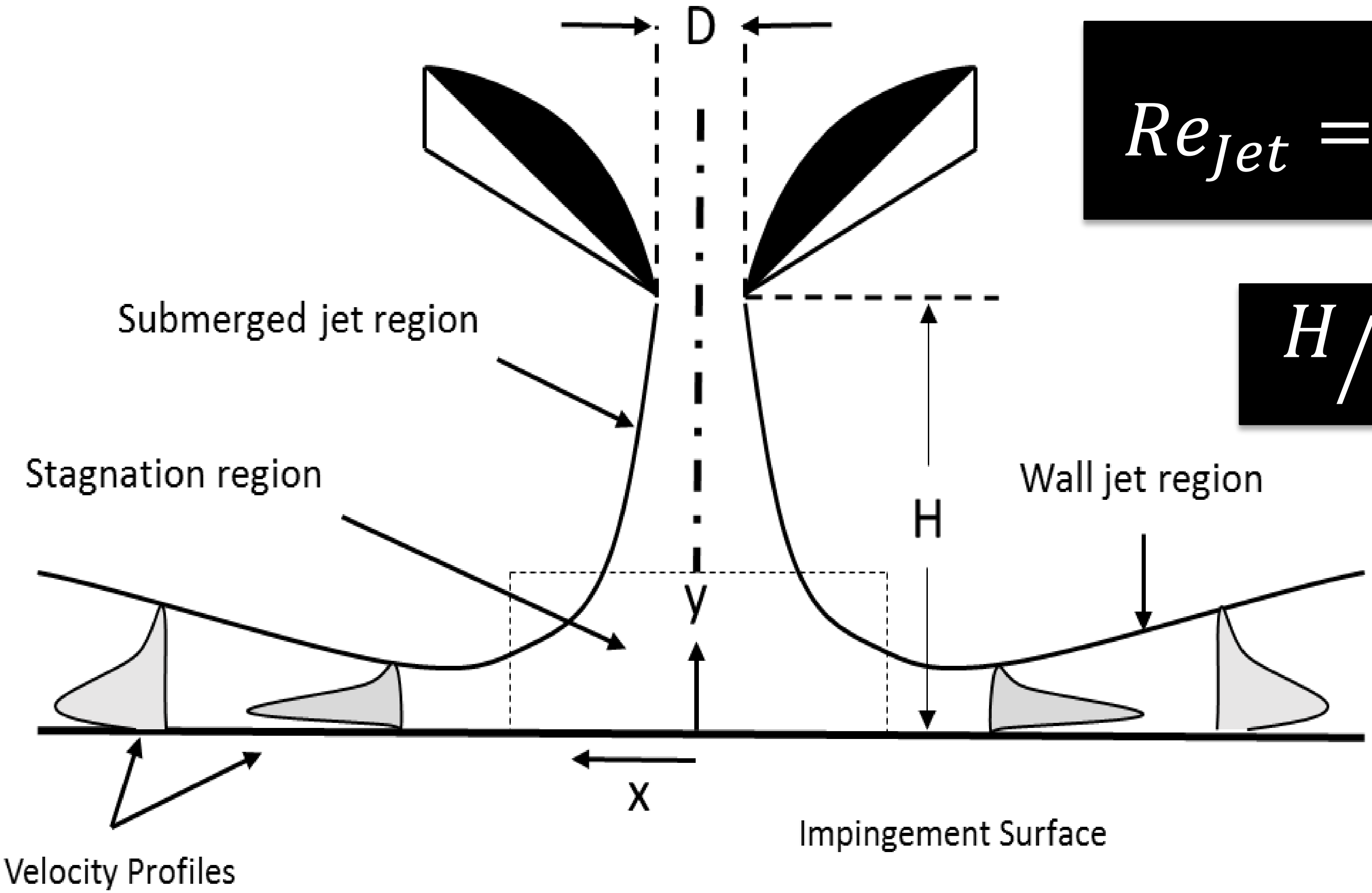
Task 2 – Measurement of Shear Stresses

- **Experimental methods available include: LDV, hotwire and hot-film anemometry, Preston tube, and oil interferometry.**

- **LDV was attempted but oil particles contaminated the information at the wall, necessary for wall shear stress calculation.**

- **Currently looking at using hot film anemometry and razor blade techniques**
  - **calibration and low Rem calibrations and measurements**

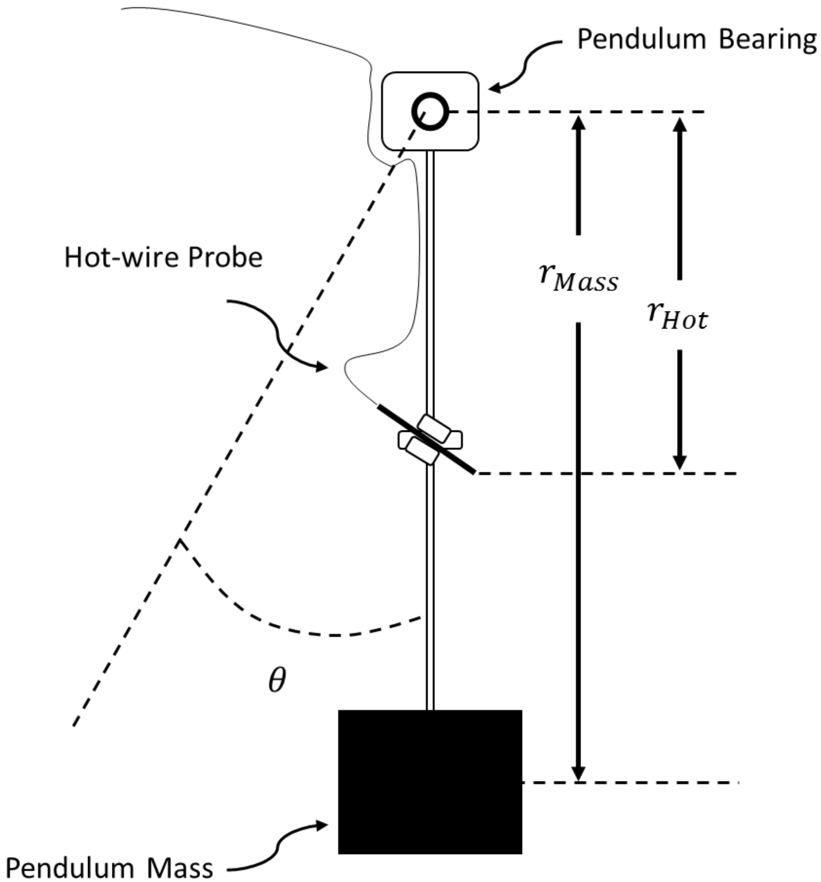
Air knife model

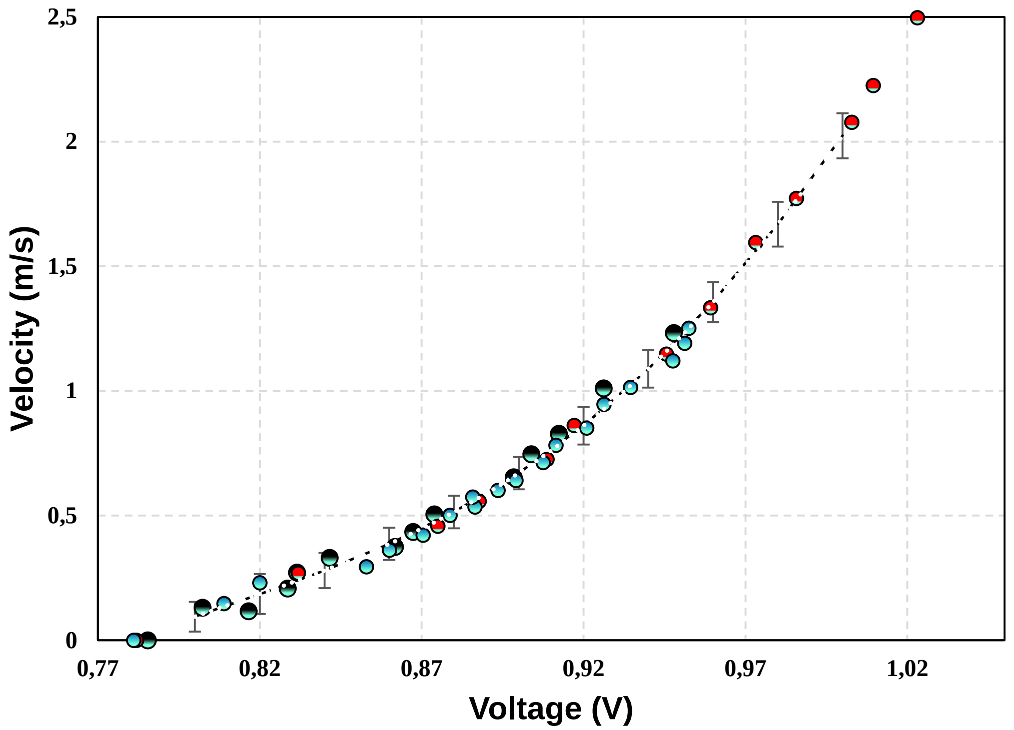


$$Re_{Jet} = \frac{U_{Jet} D}{\nu}$$

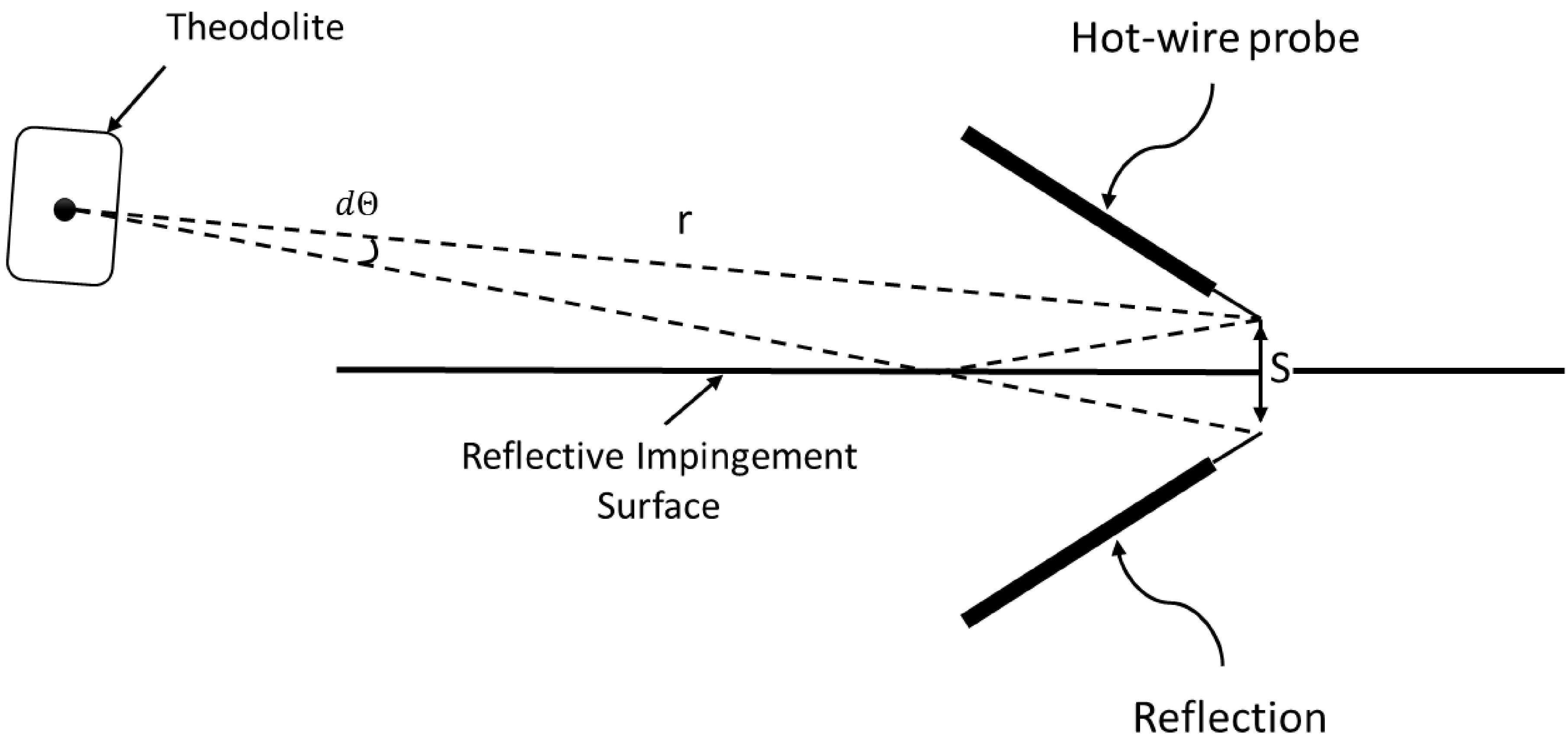
$$H/_{D}$$

Hot-wire velocity calibration

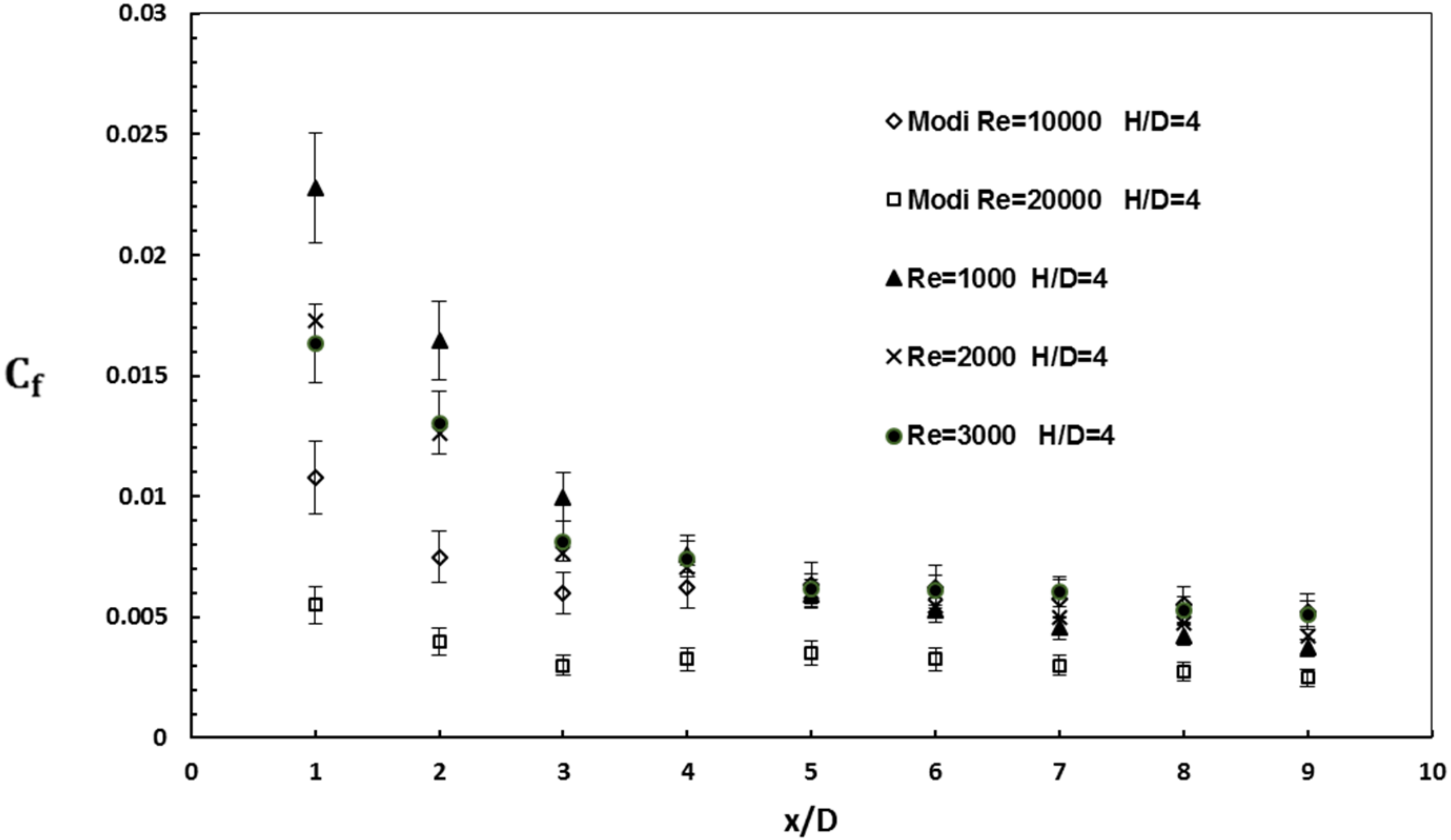




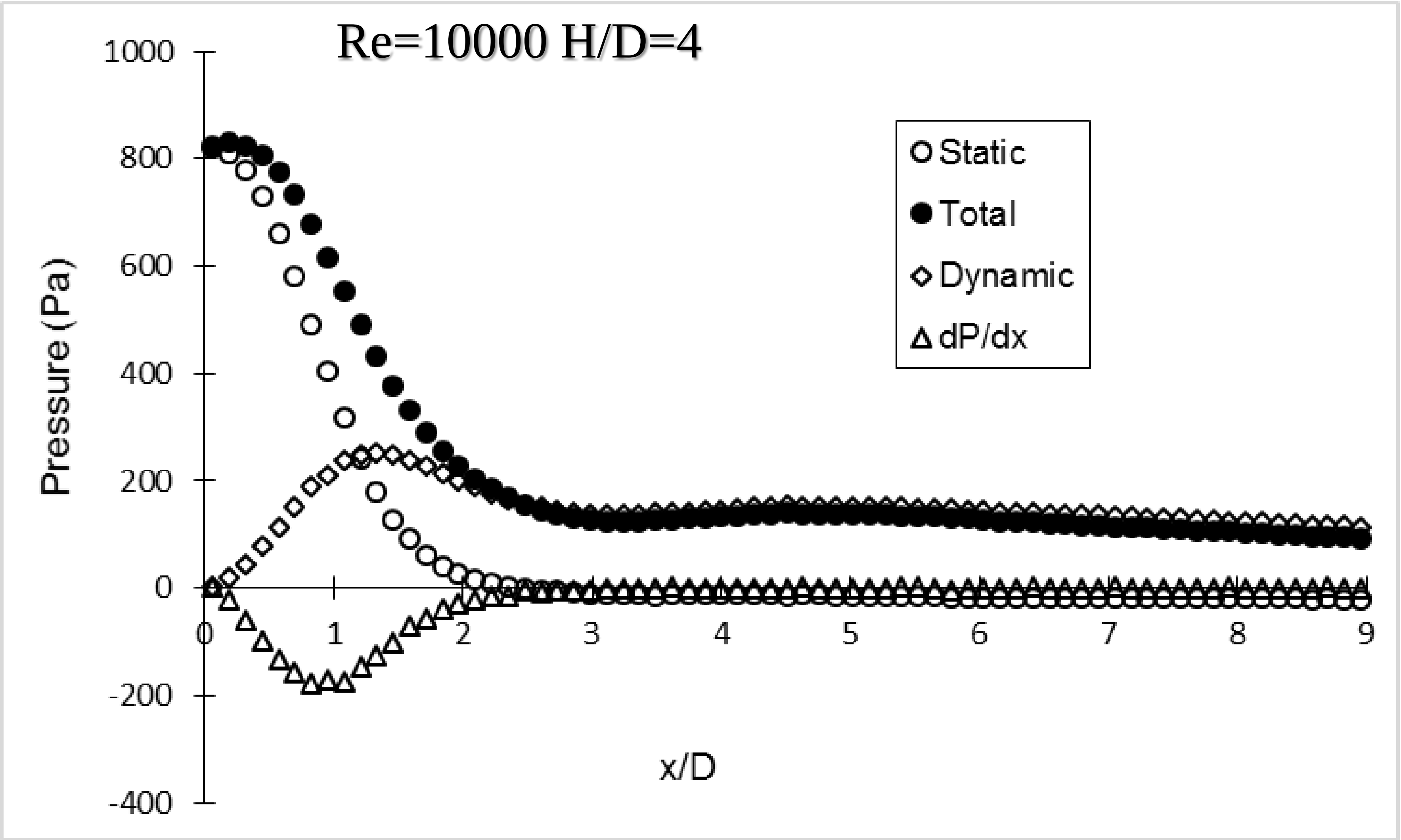
Hot Wire Wall Distance Measurements



Shear Calibration Points

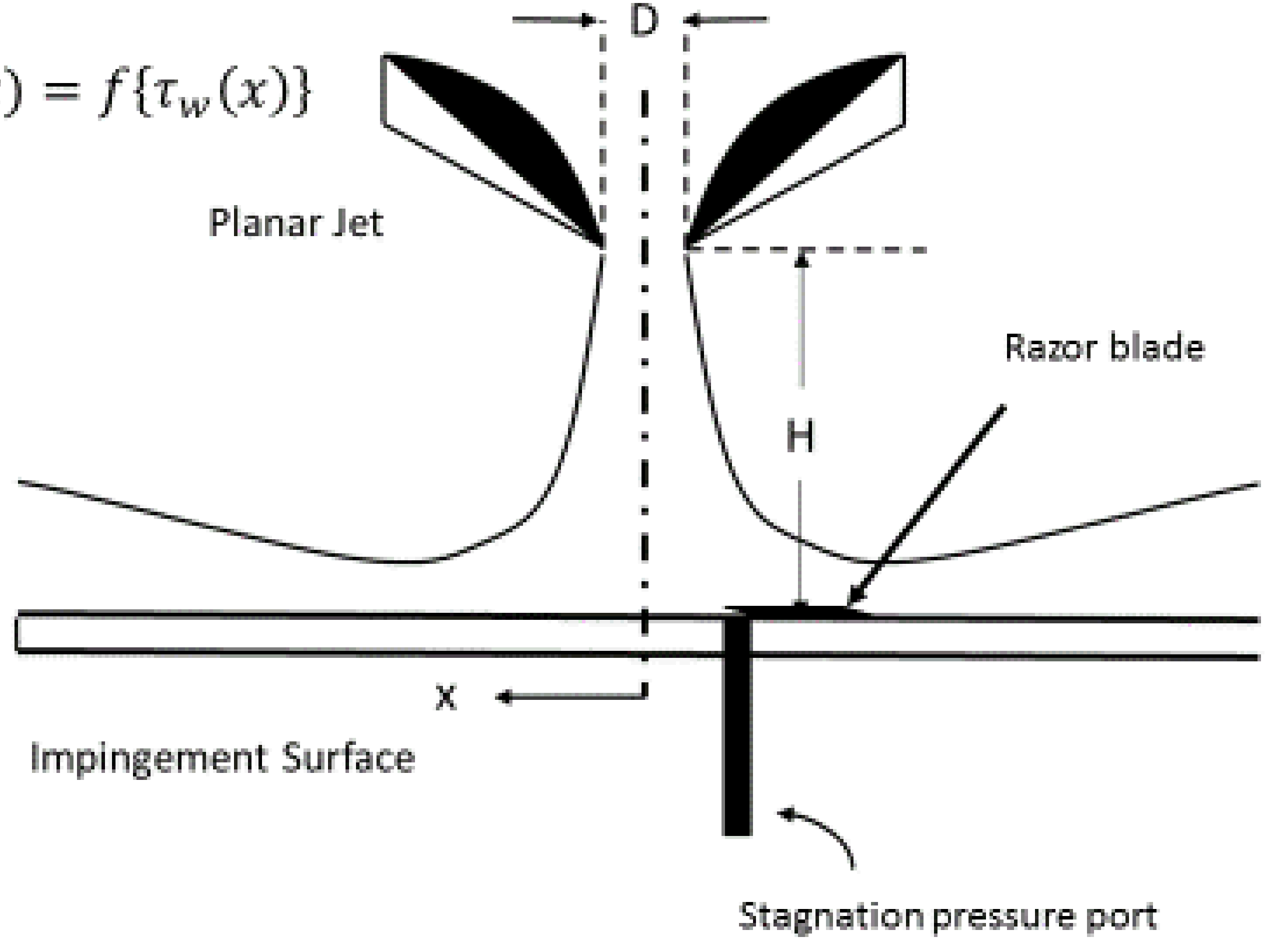


Preliminary Pressure Measurements



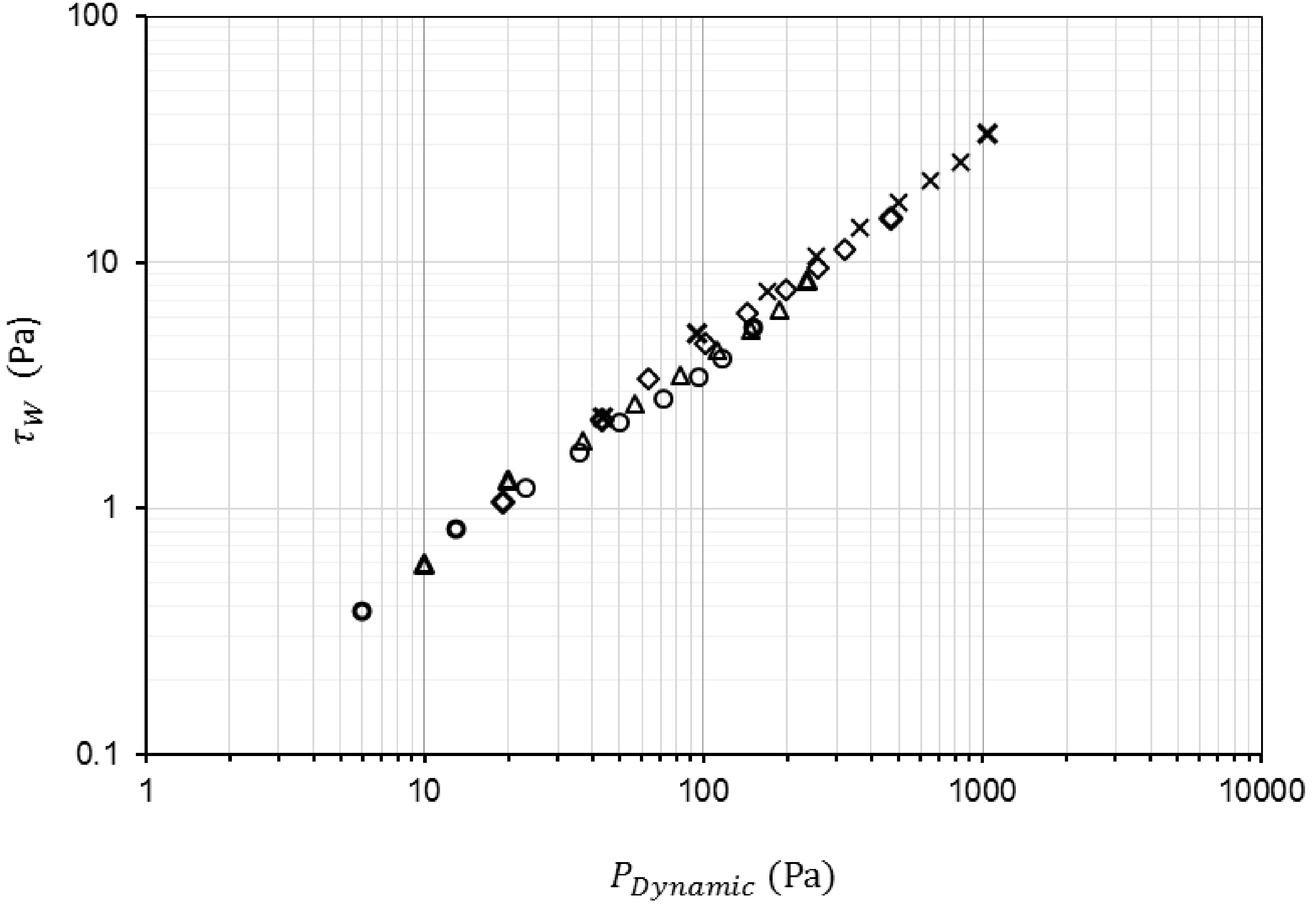
Dynamic Pressure Calibration

$$P_{dynamic}(x) = f\{\tau_w(x)\}$$



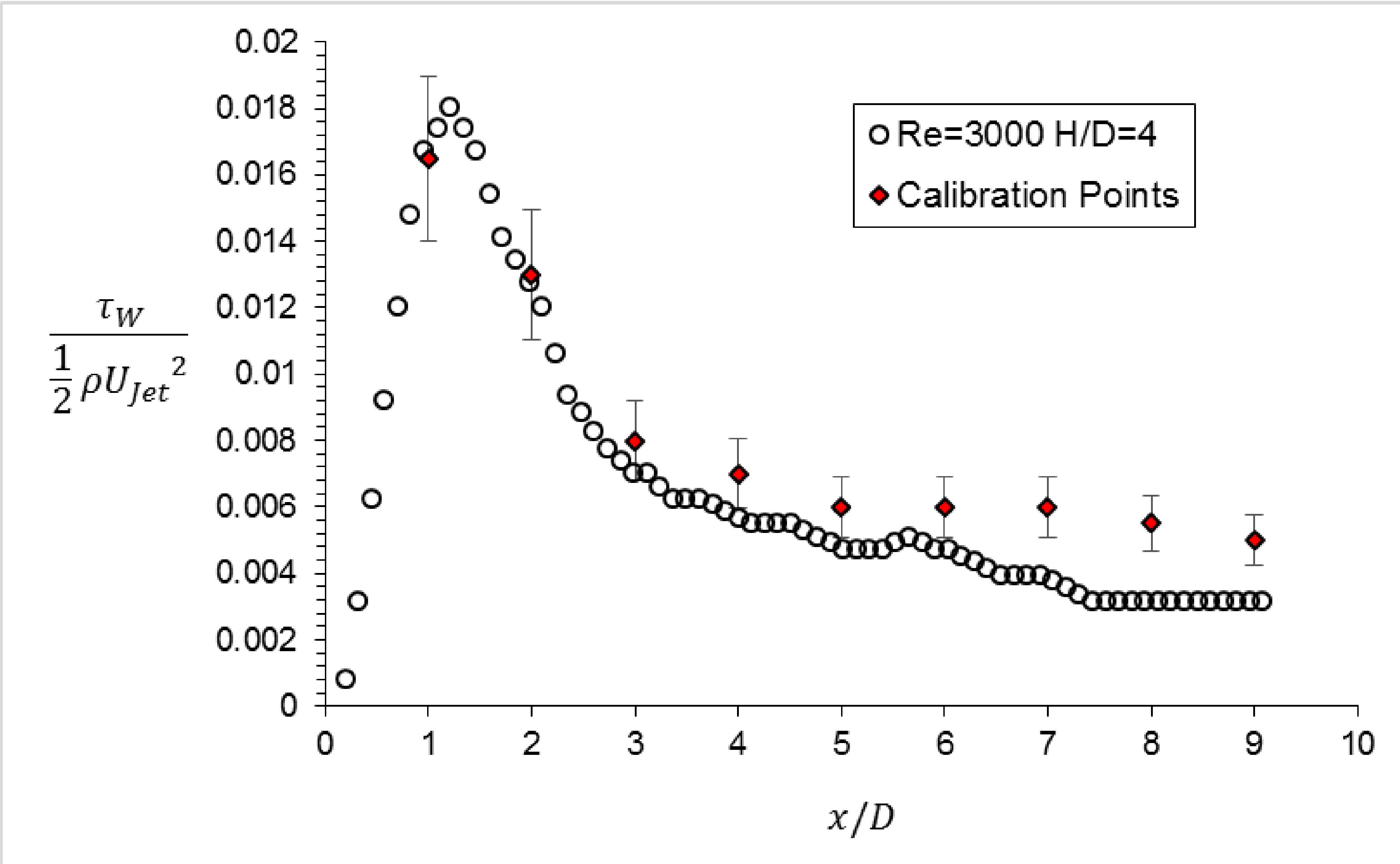
Shear Stress Calibration

Different Jet Reynolds Numbers & Jet Slot Widths: (H/D=4; x/D=1)



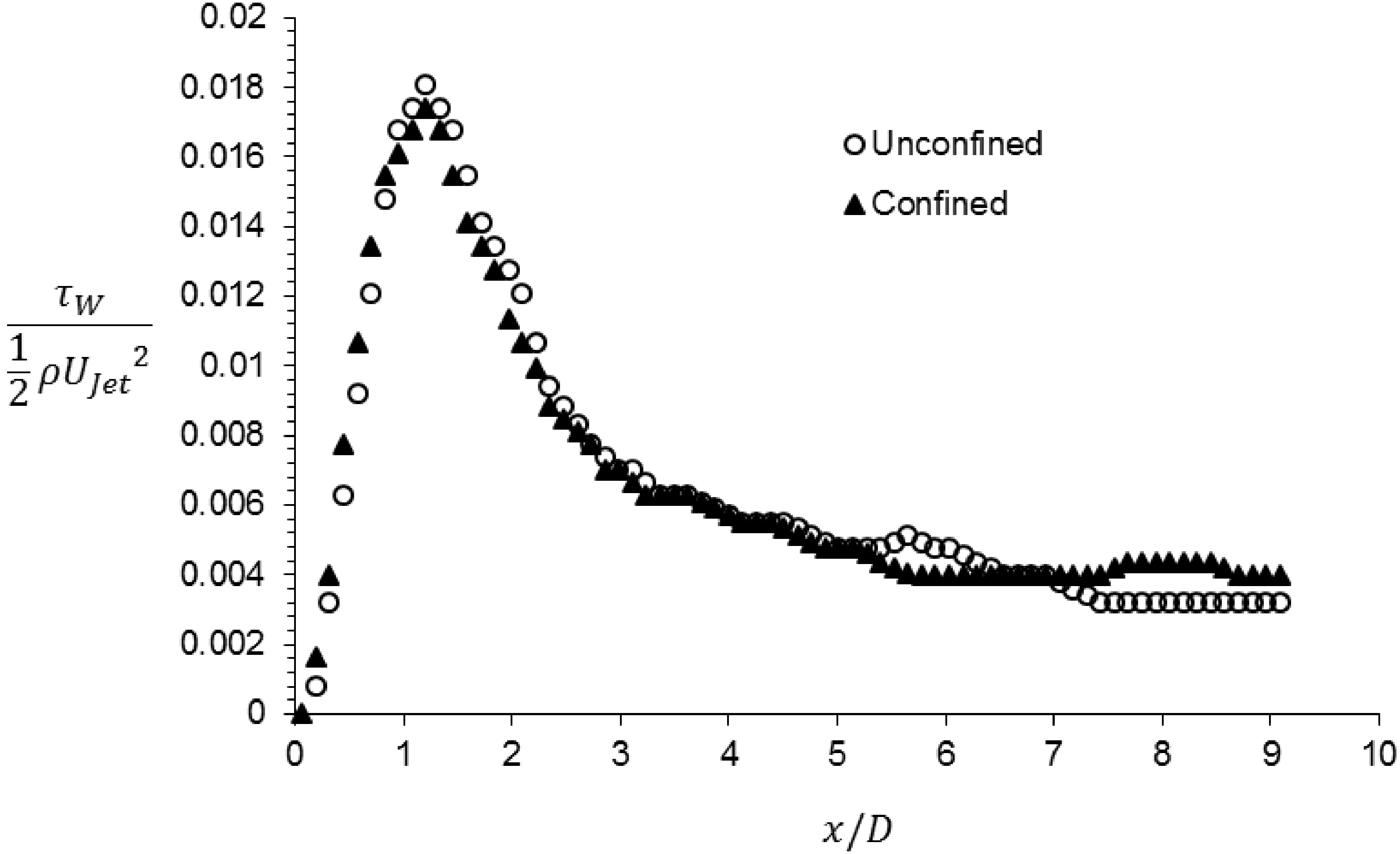
Calibration Comparison

- Agrees well in laminar region $0 \leq x/D \leq 2$
- Resolves maximum shear stress

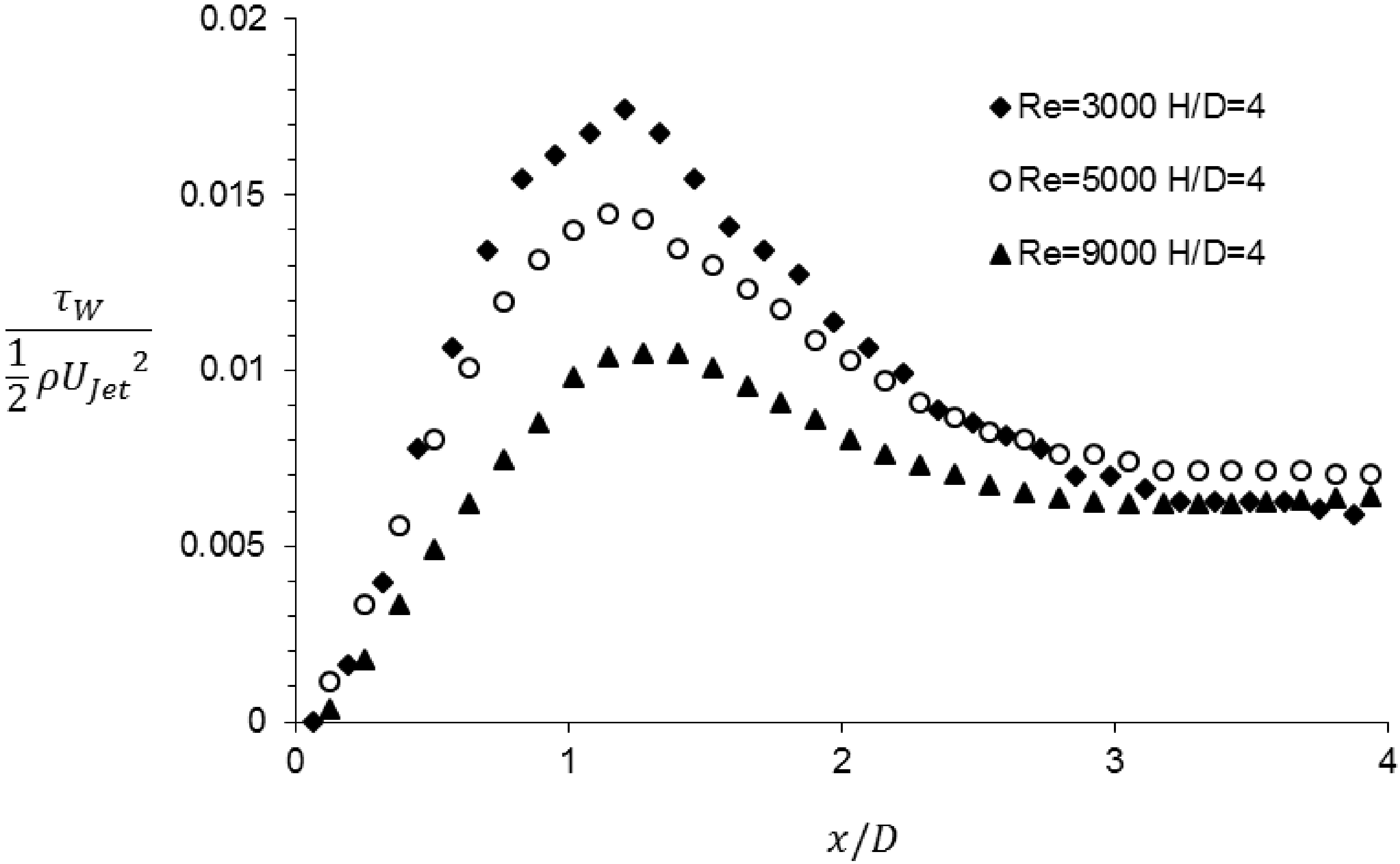


Effects of Confinement with Presence of Auxiliary Jets

Re=3000 H/D=4



Preliminary Shear Stress Measurements



Task 2 – On-going Work and Future Steps

- **Low velocity razor technique measurements of shear stresses (on-going)**
  - **complete measurements for Alibeigi pressure profile measurement conditions**
  - **multi-slot: vary $6 \leq z/d \leq 12$; $d = 1.5mm$; $s/d = 13.15$; $v_{jet} = 113.5$ m/s; $v_{aux} = 0.50$ main jet velocity (base)**
- **Lower velocity hot film anemometry studies at same conditions**
- **Scale to higher Reynolds number flows.**

Task 2 – Future Work

- **Parametric study of single and multi-slot air knives**
  - **multi-slot: vary 6 ≤ z/d ≤ 12; d = 1.5mm (base case), 1.0mm; v_{jet} = 113.5 m/s (base), 200m/s, 300m/s; v_{aux}= 0.50 main jet velocity (base)**
  - **multi-slot: vary velocity and jet-plate distance (s/d) of auxiliary jets; s/d = 13.15 (base), 5, 10; independent v_{aux}**
  - **measure pressure profiles and shear stresses for input into coating model**

Task 3 – Extension of CFD Models

- MASc student arrived in September – Ali Yahyae
- Will commence with meshing single and multiple jet geometries according to our experimental jet CAD drawings
  - check agreement with measured pressure profiles of Alibeigi from Task 1
  - tune k-ε model if required to obtain agreement
  - obtain shear stress profiles per experimental work of Ritcey in Task 2
- Proceed with modelling of Zn-Al-Mg coating wiping

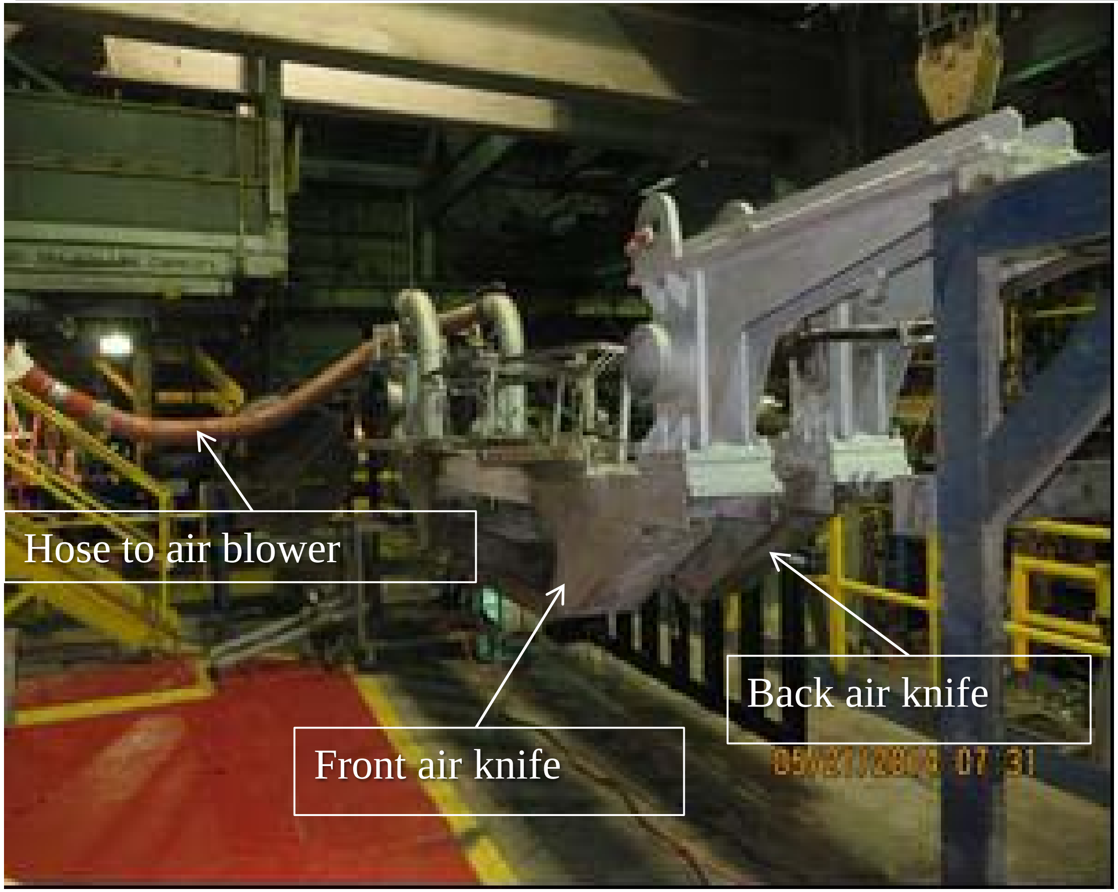
Task 4 – Pressure Profiles on AMD Air-Knives

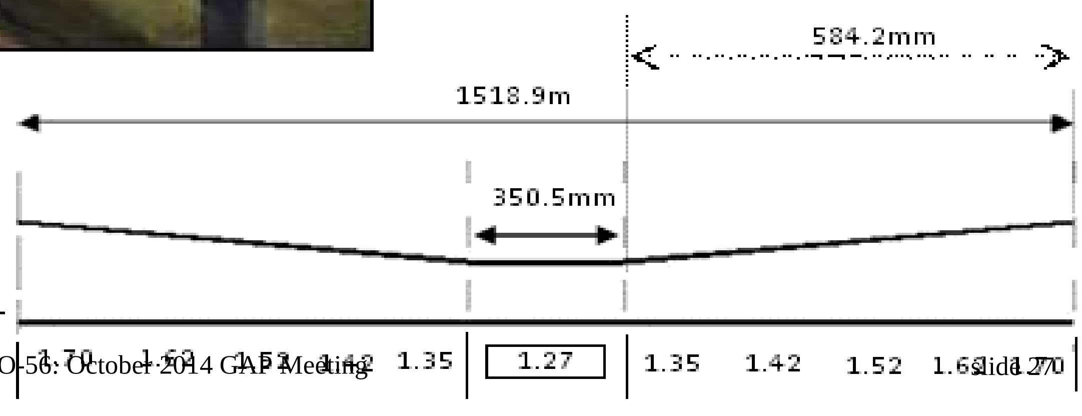
- **Task 4: Full scale testing at the facility of AM Dofasco**
  - **offline pressure profile and pressure uniformity measurements on AM Dofasco production knives – CGL#1**
  - **used a spare production blower**
- **Rig constructed for use with AM-Dofasco air knives**
  - **comprises a frame with a movable impingement plate and pressure transducer**
- **Trials conducted over summer 2014**

Objectives

- **Characterize pressure profiles along and across the exit of the air knife for different air knife pressures and *z/d***
- **Determine the effect of screens on air knife pressure profiles**

Experimental Facility at # 1 CGL

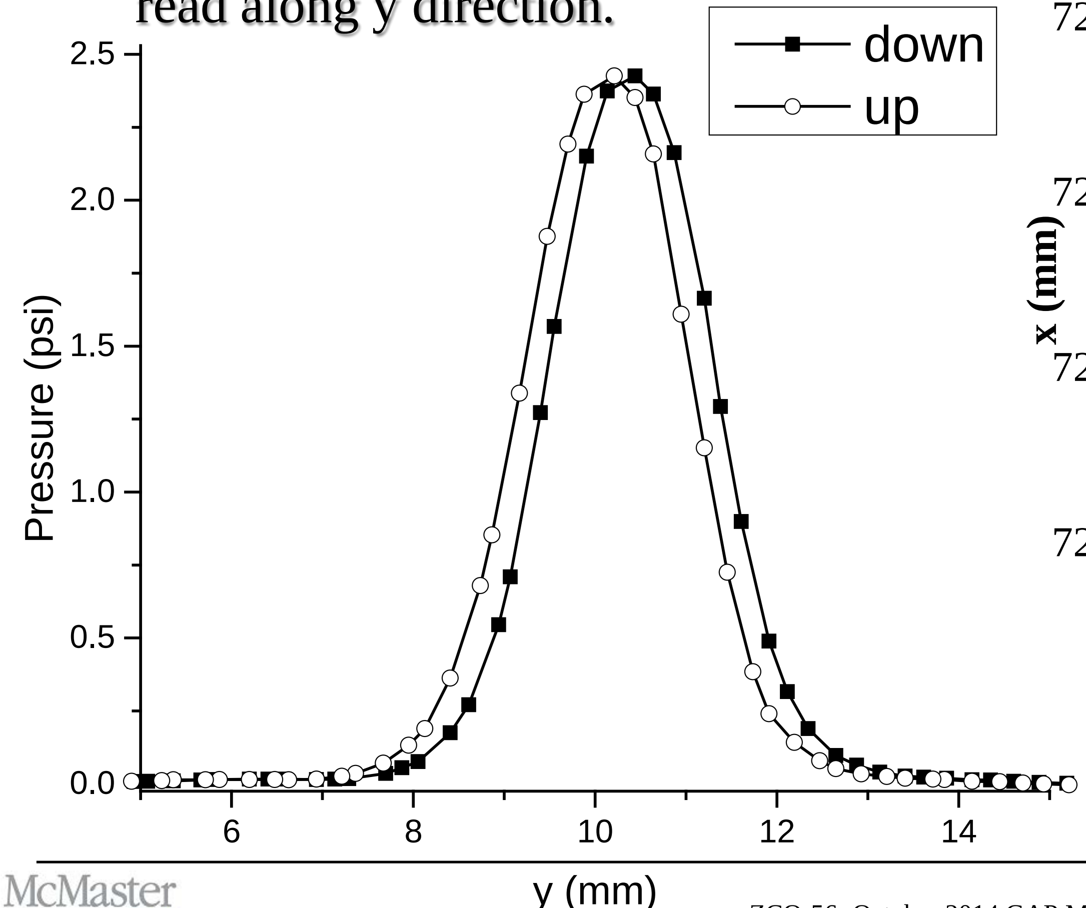




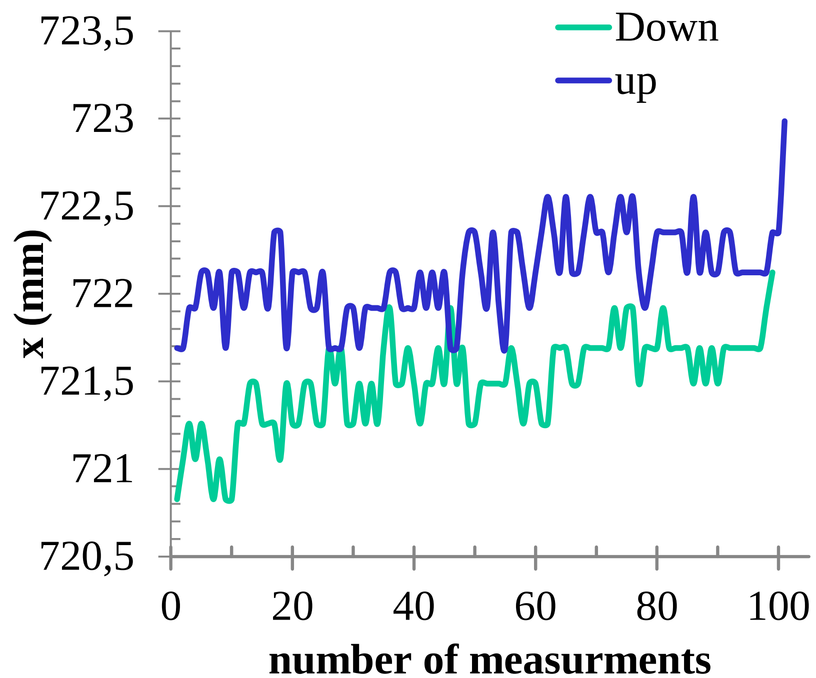
CGL#1 air knife gap profile

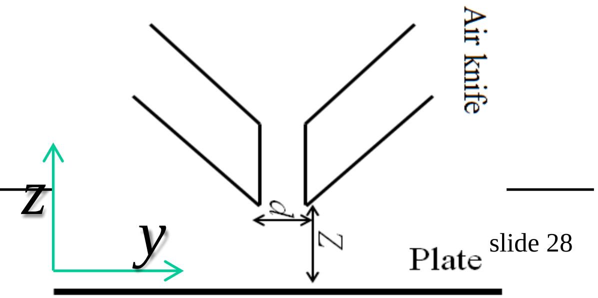
Results – z/d = 4, P = 2.53 psi

- The pressure profile had a Gaussian shape.
- Although the plate was at the potential core, the maximum pressure was slightly less than the plenum pressure.
- The plate moved slowly along the x direction while the pressure data were being read along y direction.



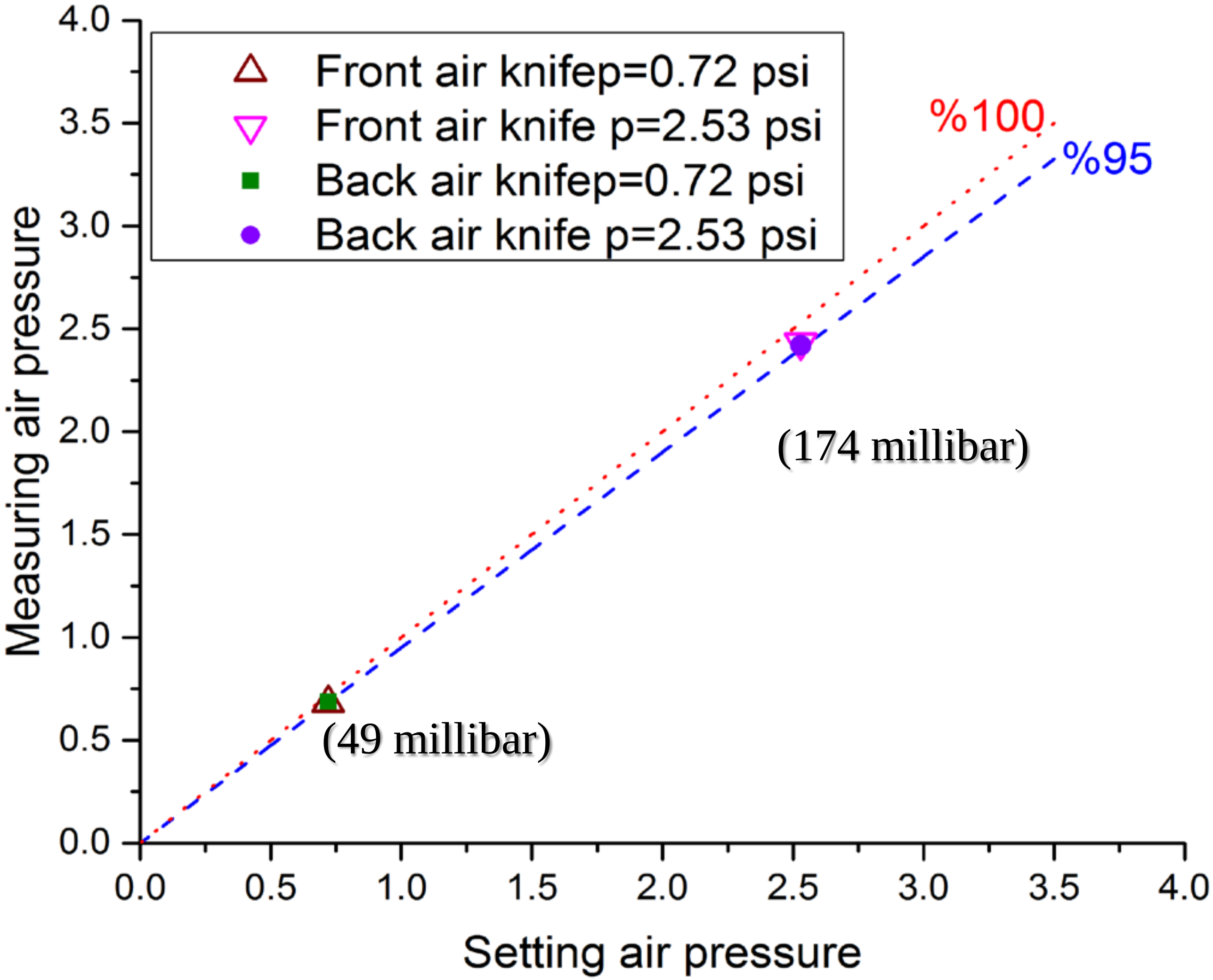
z/d=4 P=2.53 psi (174 millibar)





Results – Pressure Recovery from Core

- Maximum %5 error which is a significant improvement compared to previous trials



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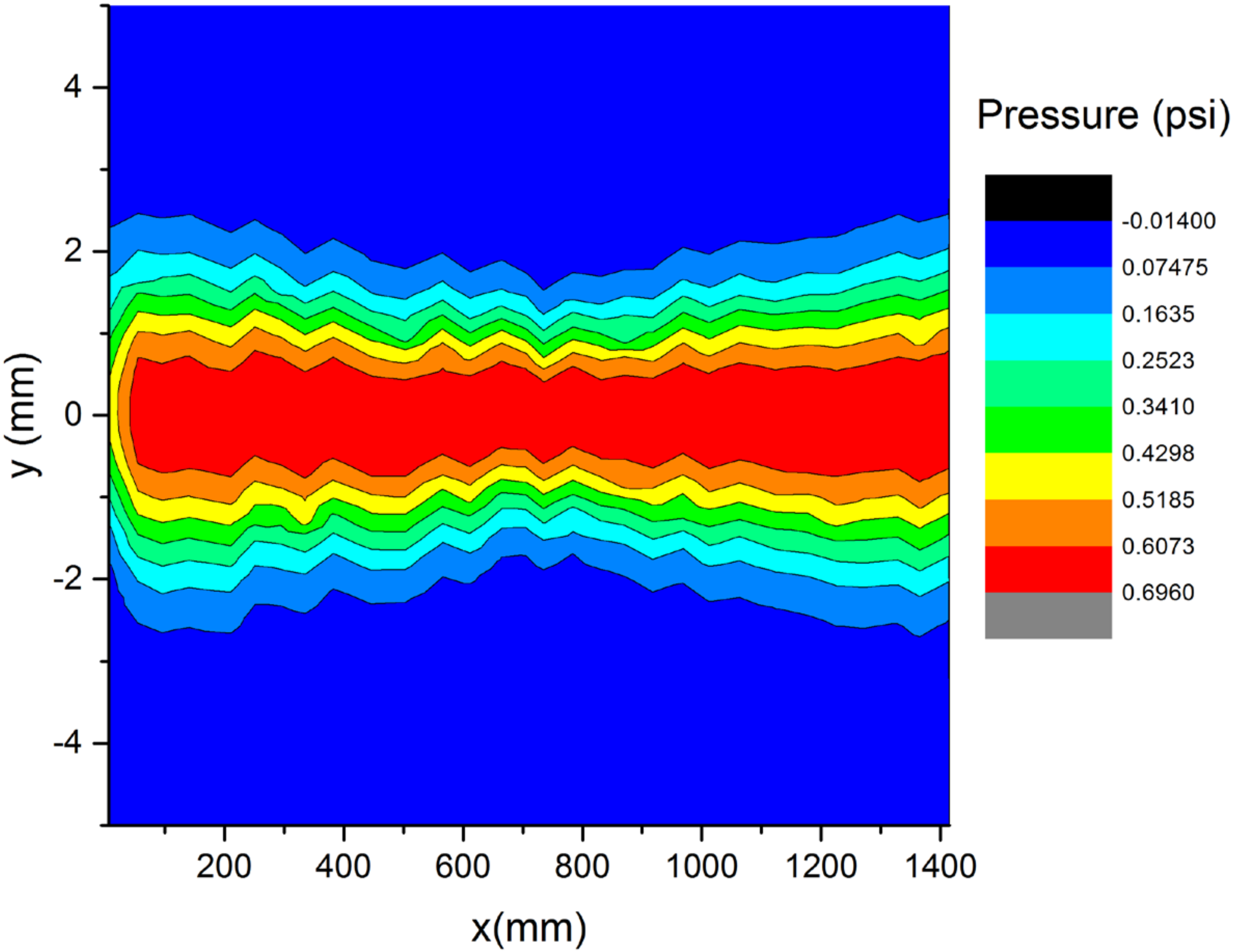
Results – Pressure Contours

- Pressure contour at z/d=4 and p=0.72 psi



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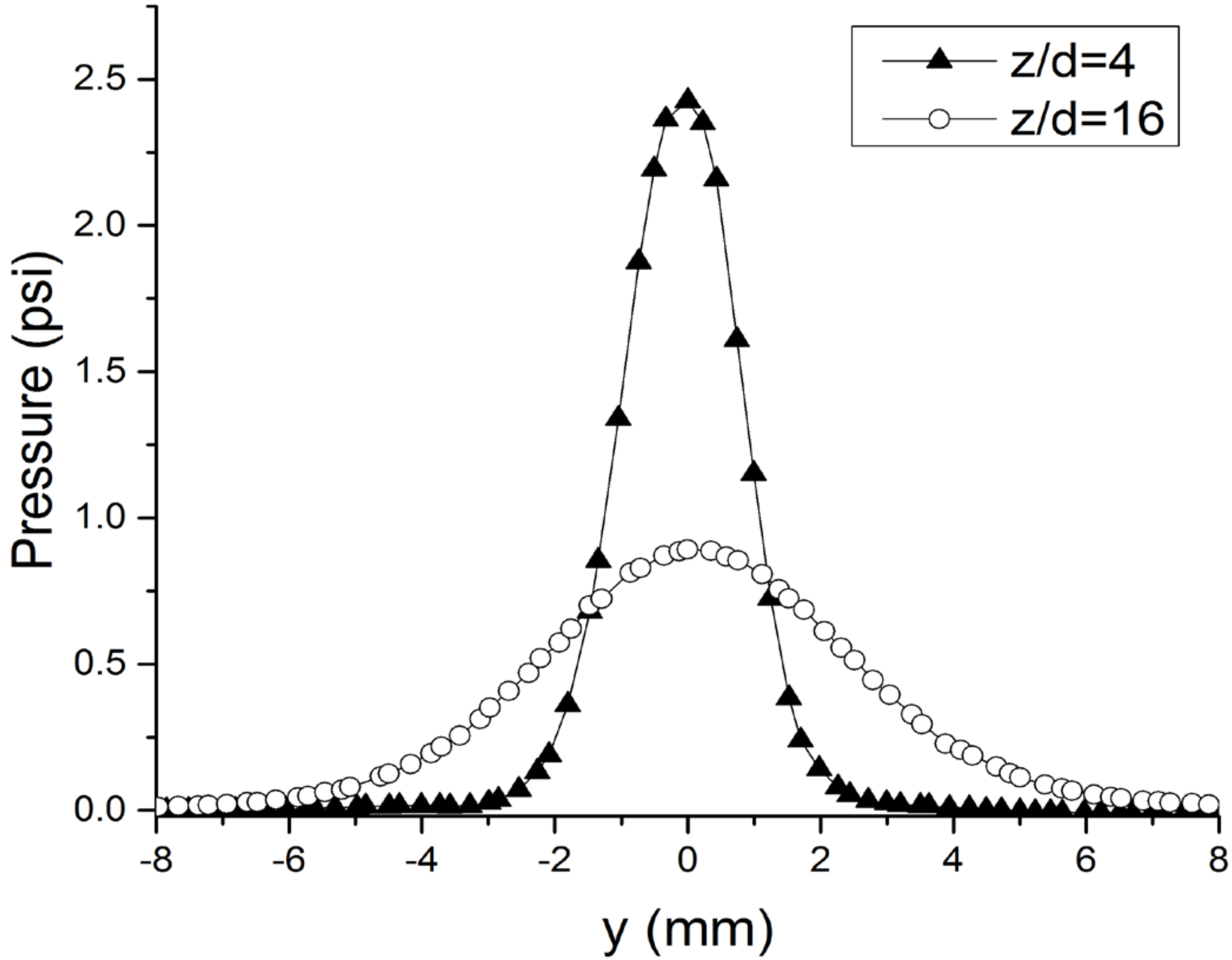
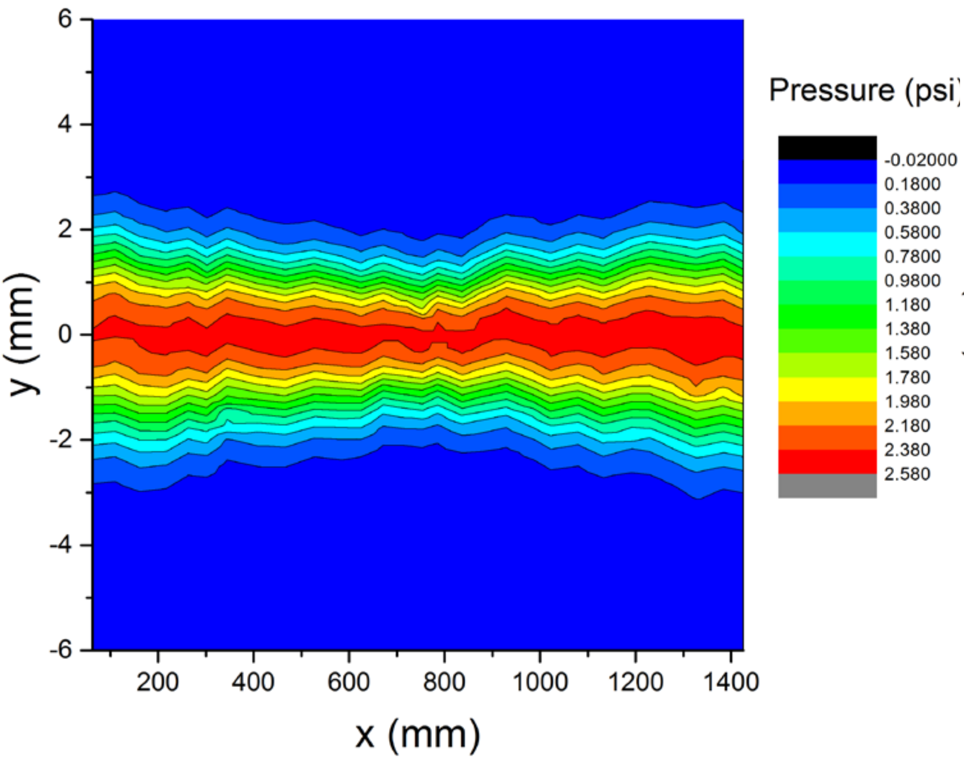
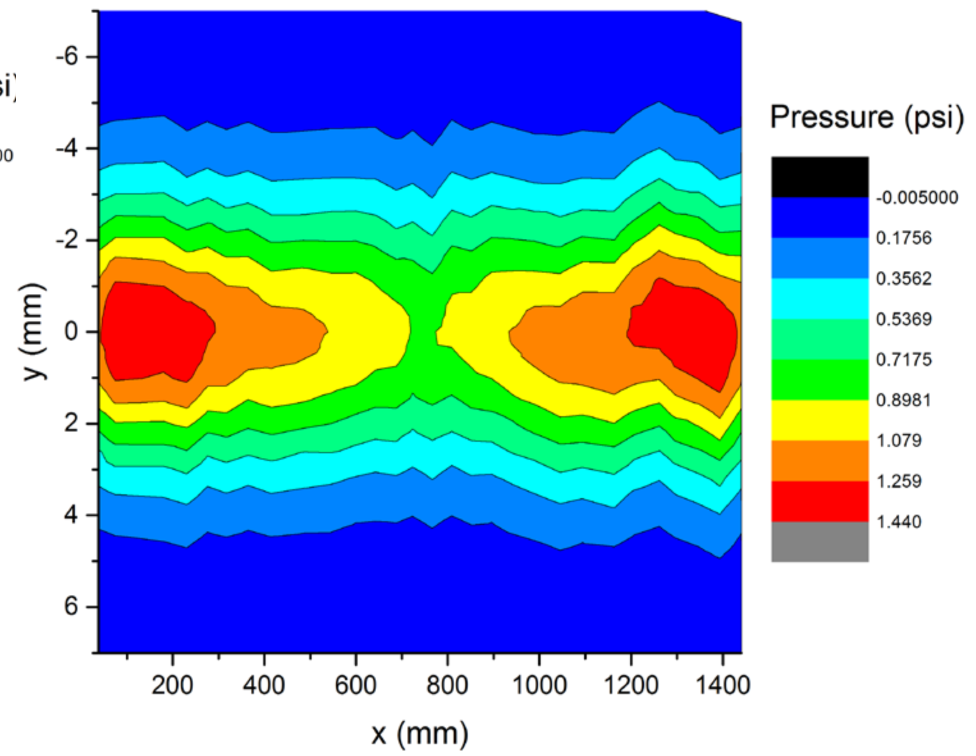
Results – Effect of *z/d* on Pressure Profiles



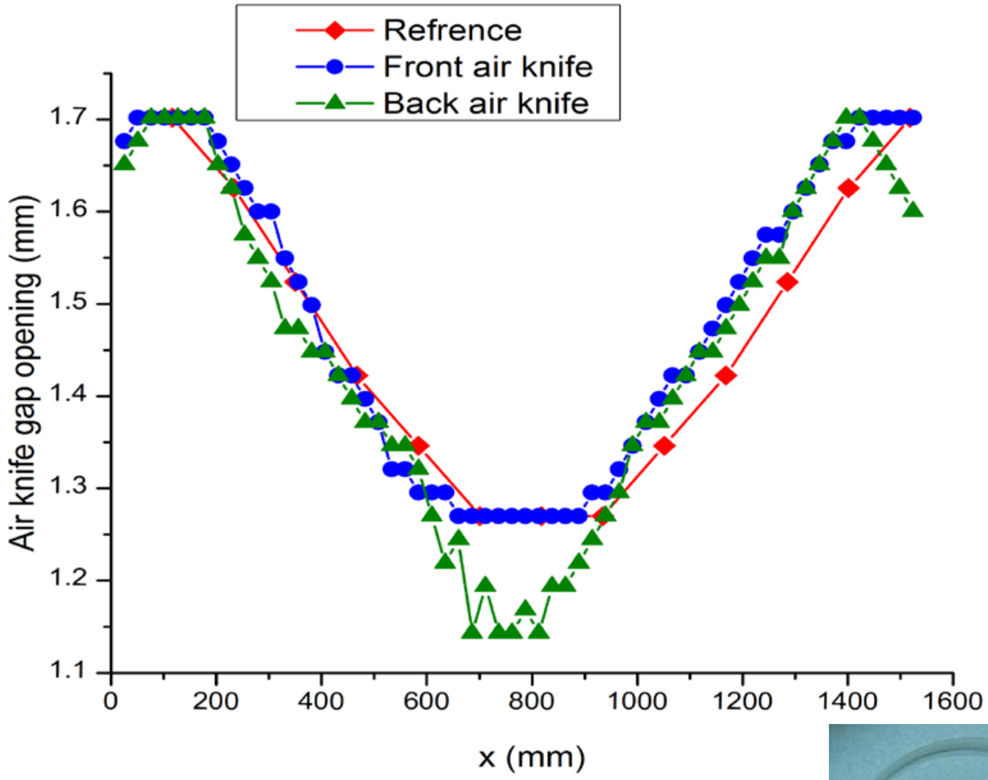
Results – Effect of *z/d* on Pressure Profiles

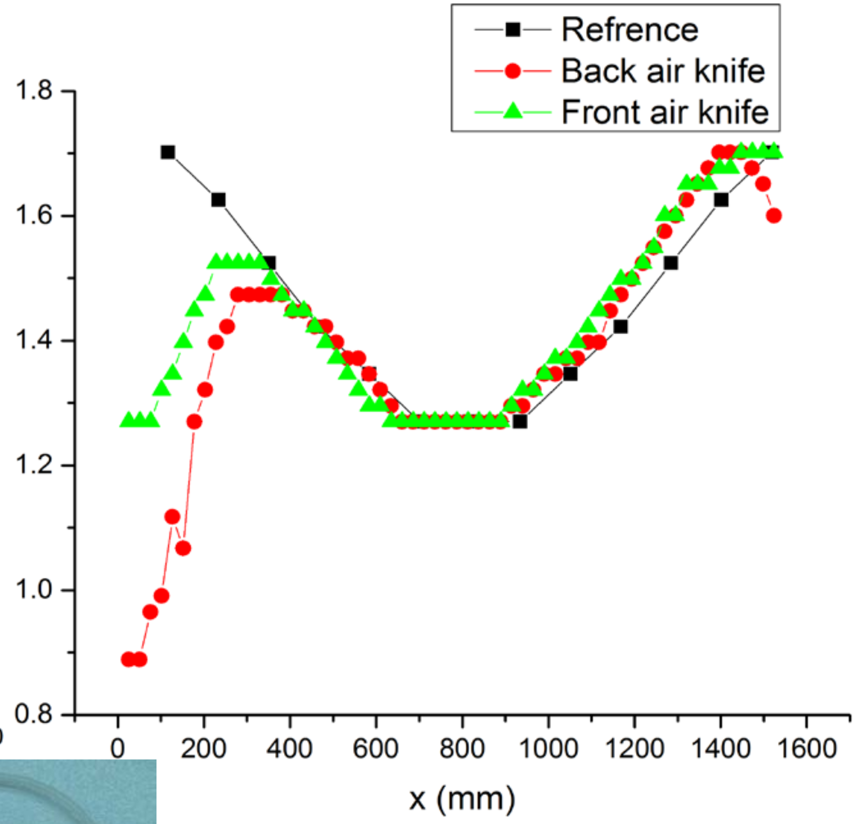




z/d=4 *p*=2.53 psi (174 millibar) *z/d*=16 *p*=2.53 psi (174 millibar)

Results – Air Knife Gap Opening



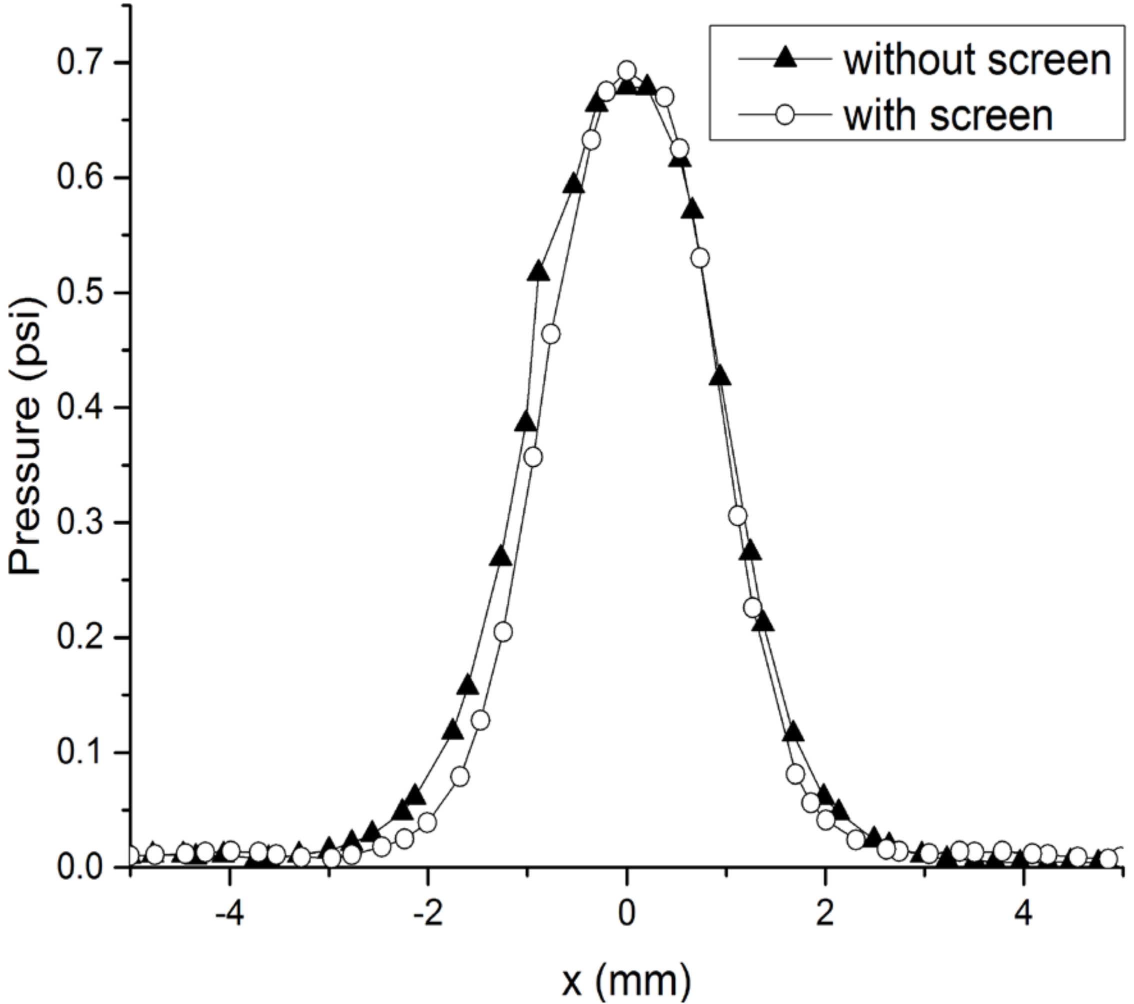


pressure gauge rod is in the **middle** of the air knife

pressure gauge rod is at the **left end** of the air knife

Results – Effect of Internal Screens on Pressure Profiles

- Maximum pressure value very slightly higher with screens
- Pressure profile for the air knife without the screen is a little bit wider than that of the air knife with screen.



Task 4 - Summary

- The maximum impingement pressure had 95% recovery in the jet potential core
- By increasing the distance between the plate and the air knife the maximum pressure decreased, and pressure profile became wider.
- The pressure gauge rod changes the air knife gap opening.
- The screen makes the pressure profile becomes a little bit sharper, and less wide - positive effect on *dp/dy* value of the coating weight model
- Was able to measure pressure profiles across width of the air knife

Task 4 – Future Work

- **Perform additional trials at Dofasco using air knives from other CGLs and enlarge the measurement matrix to intermediate values of z/d and plenum pressure**
  - **some internal issues at Dofasco with retirement of personnel and parental leaves → require new project champions**

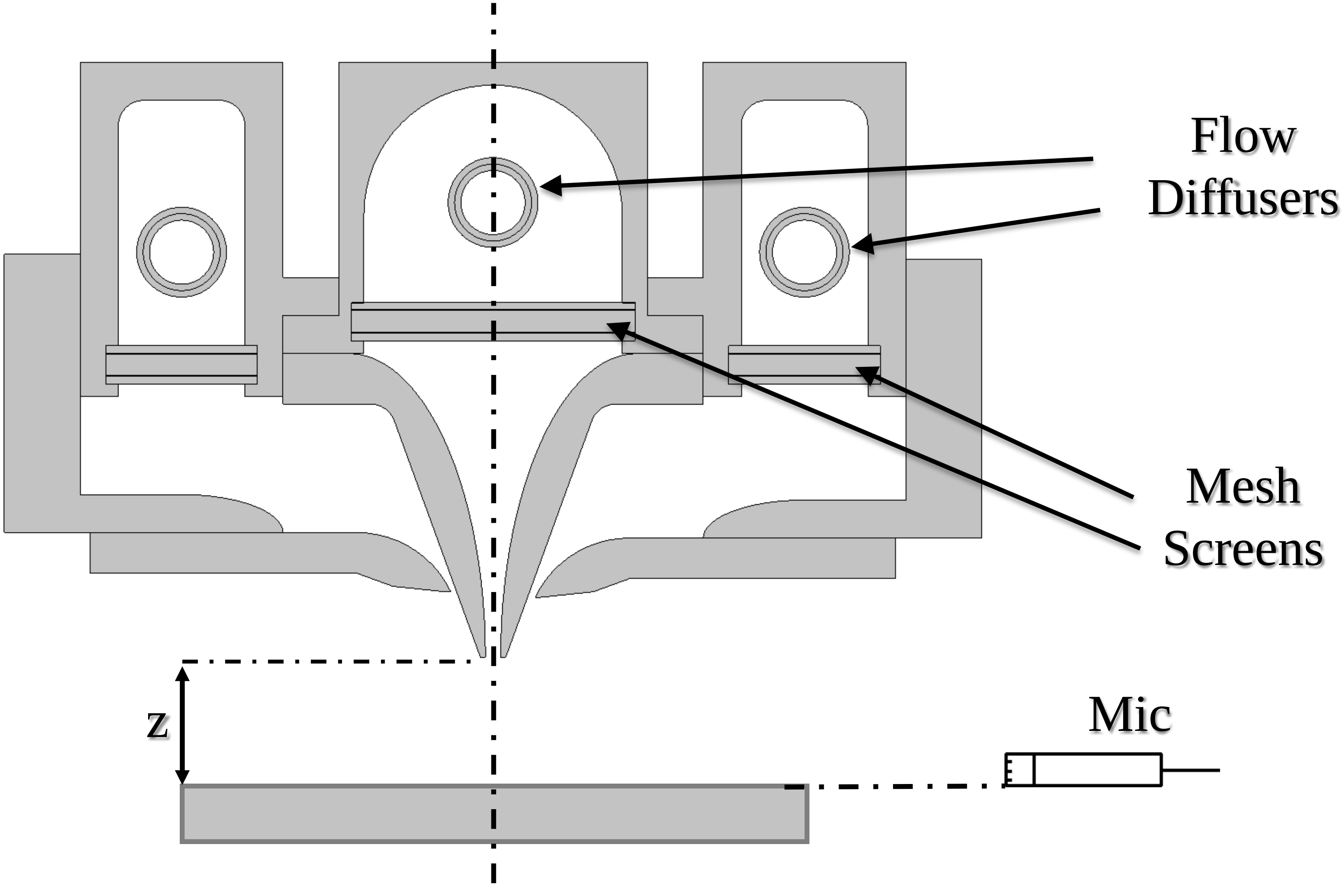
Task 5 – Unsteady Air Knife Flows

- **Fundamental understanding of unsteady flow effects on coating quality and noise generation**
  - **will explore the effect of unsteady/transient flow phenomena on coating weight uniformity and noise as a function of air-knife operating parameters (plenum pressure (jet velocity), *z/d* etc.**
  - **will make extensive use of stereoscopic PIV and dynamic pressure transducers to measure flow variations**
  - **using multi-jet design in both single and multi-jet operating modes**

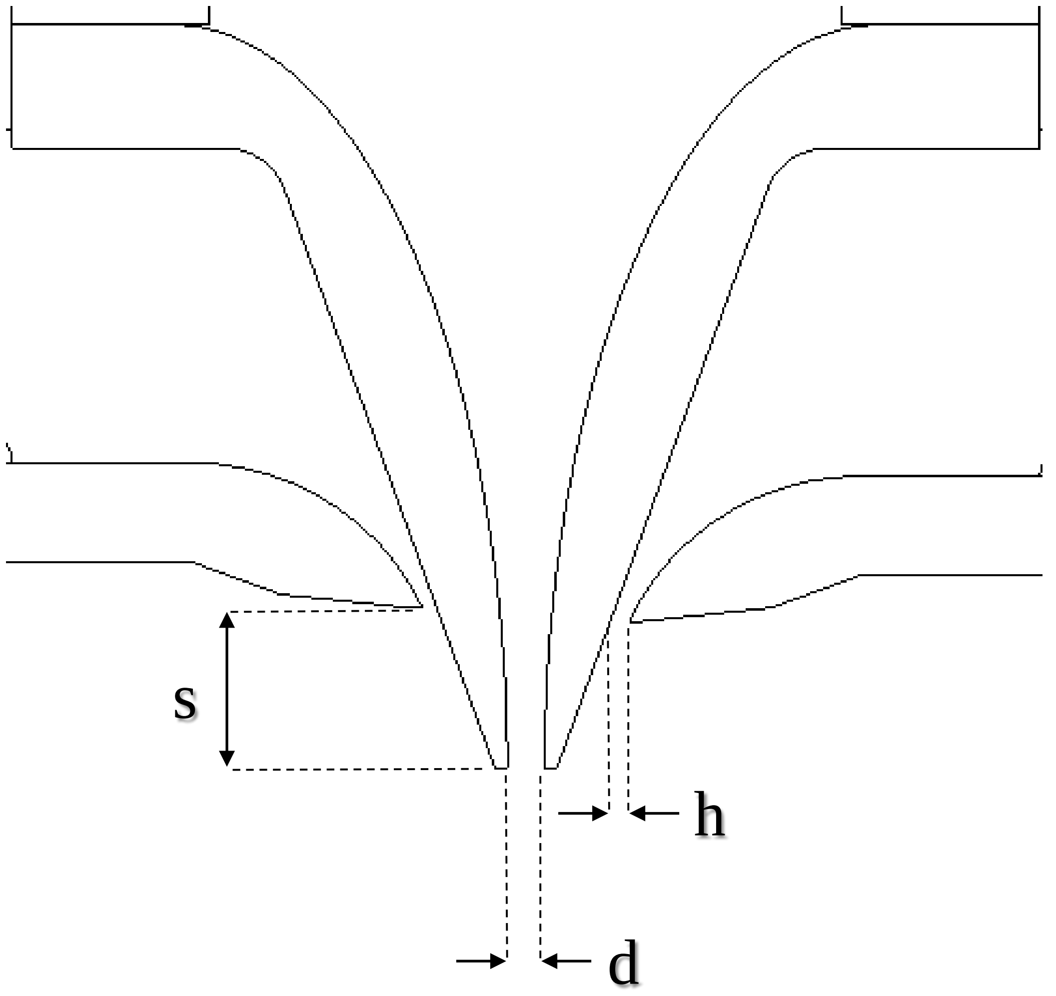
Task 5 – Unsteady Flows in Air Knives

- **To understand how the auxiliary jets may suppress noise, the noise produced by the central jet alone must be quantified and characterized.**
- **Once the noise produced by the central jet has been completed, the effect of the auxiliary jets can be quantified and the mechanism investigated.**

Experimental Setup



Jet Geometric Properties



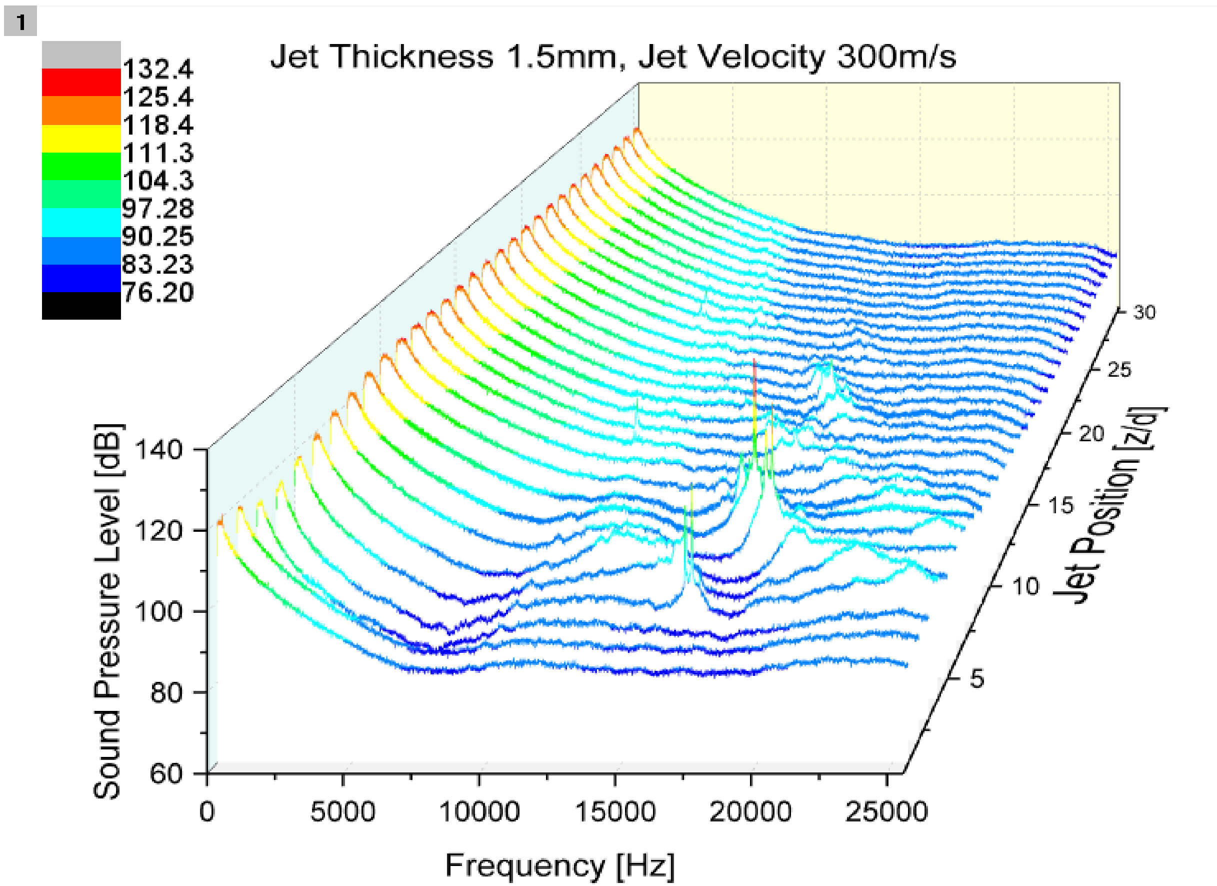
d : Thickness of the Main Jet

h : Thickness of the Auxiliary Jet

s : Nozzle Lip relative distance

Problems with Jet Noise

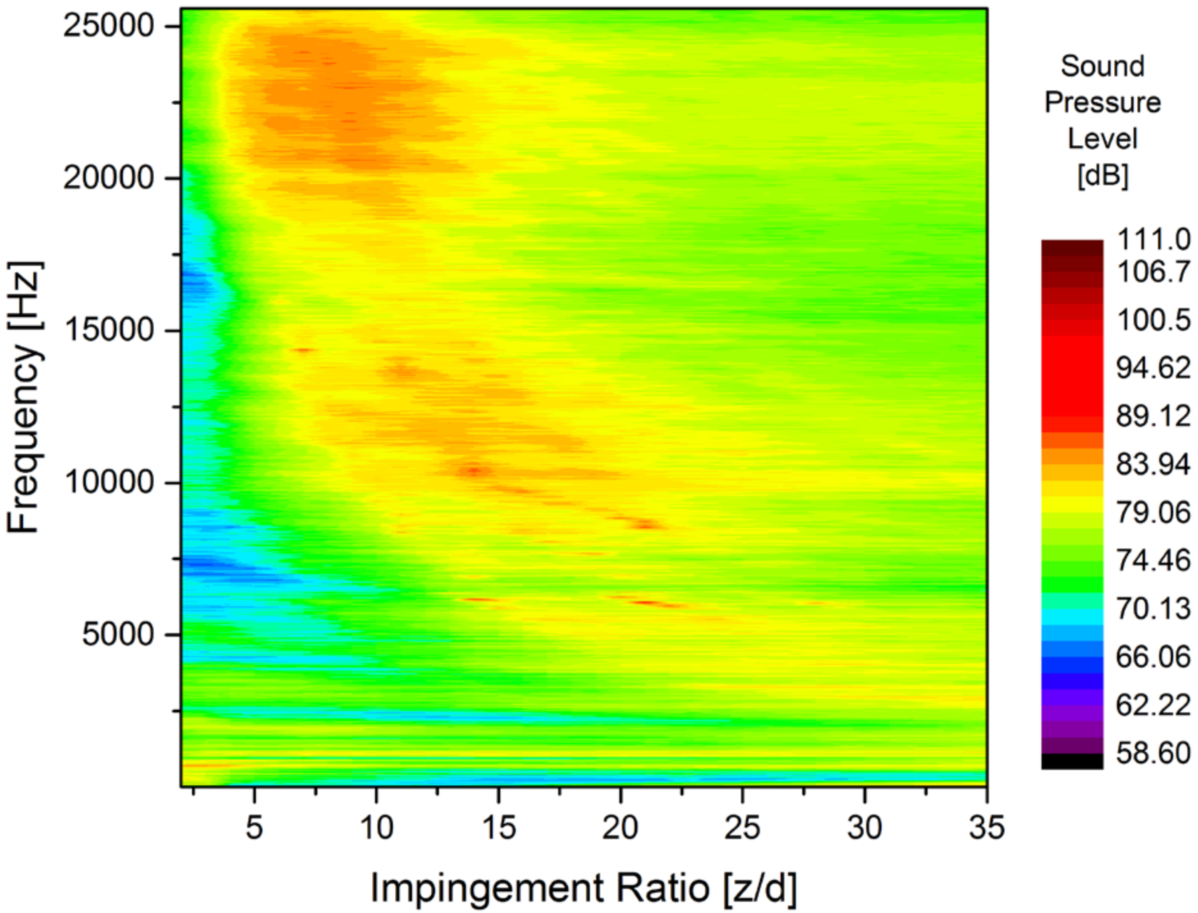
- **Magnitude and character of noise was significantly different to that of single jet work of Arthurs**



- magnitude of peaks was smaller vs. Arthurs
- quality of peaks were not as high as Arthurs
- peaks were not as consistent as Arthurs

Confinement Effects on Noise

Varying Nozzle Lip Relative Distance



$V_{MAIN} = 300$ m/s

d = 2 mm

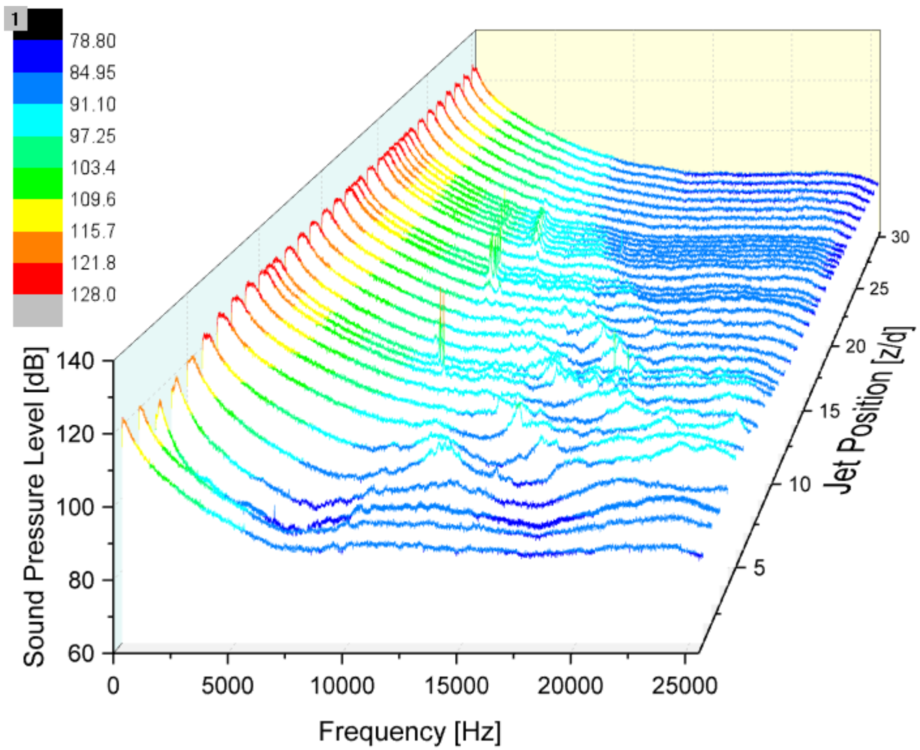
h = 0 mm

$0 \le s \le 6.0$ mm (increments of 1.5mm)

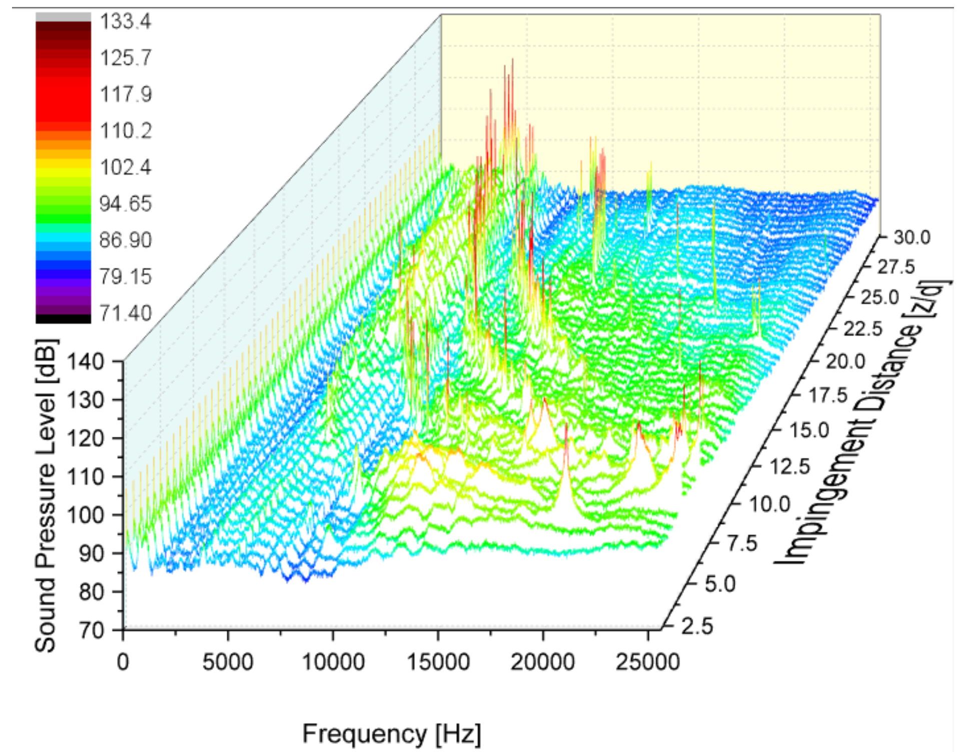
Comparison of Shortened and "Long" Jets

V_{MAIN} = 300m/s   d=2mm

"Long" Main Jet Nozzle

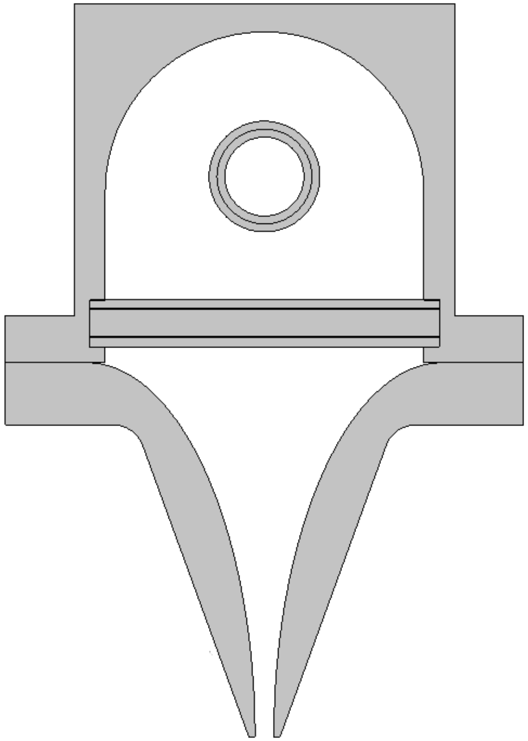


Shortened Main Jet Nozzle

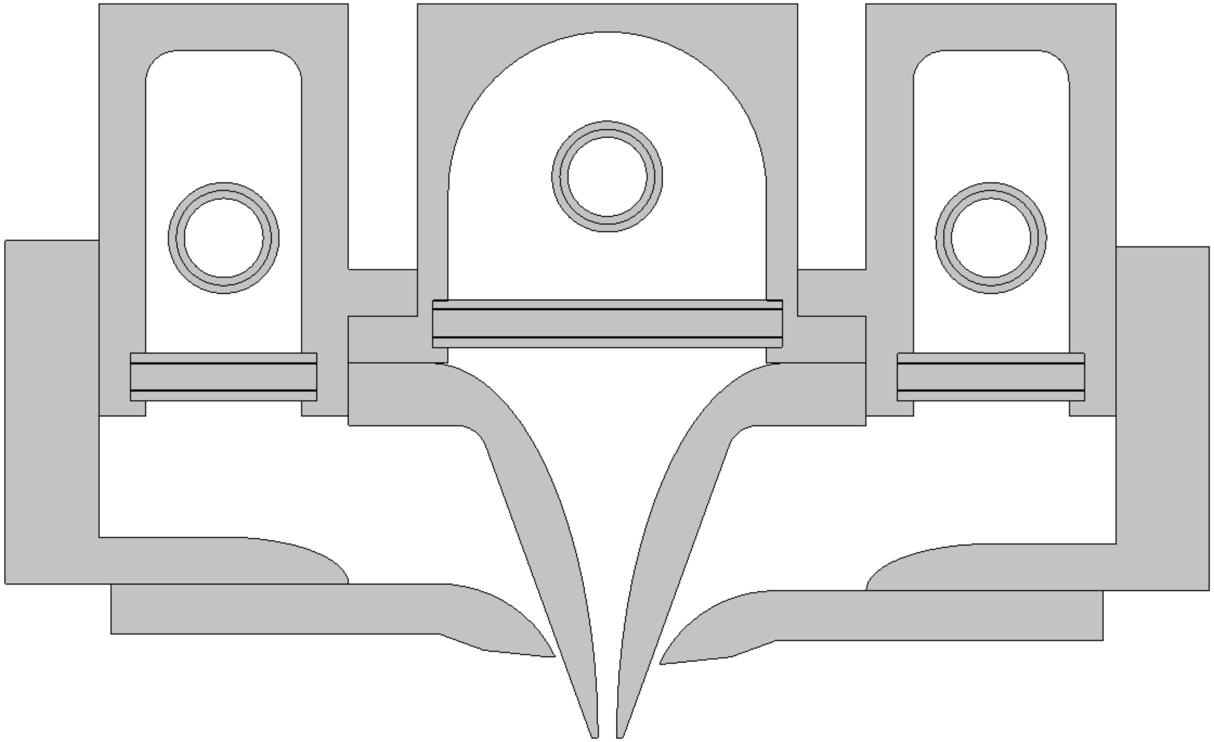


Unconfined vs. Confined Jets

Main Jet
(Unconfined)

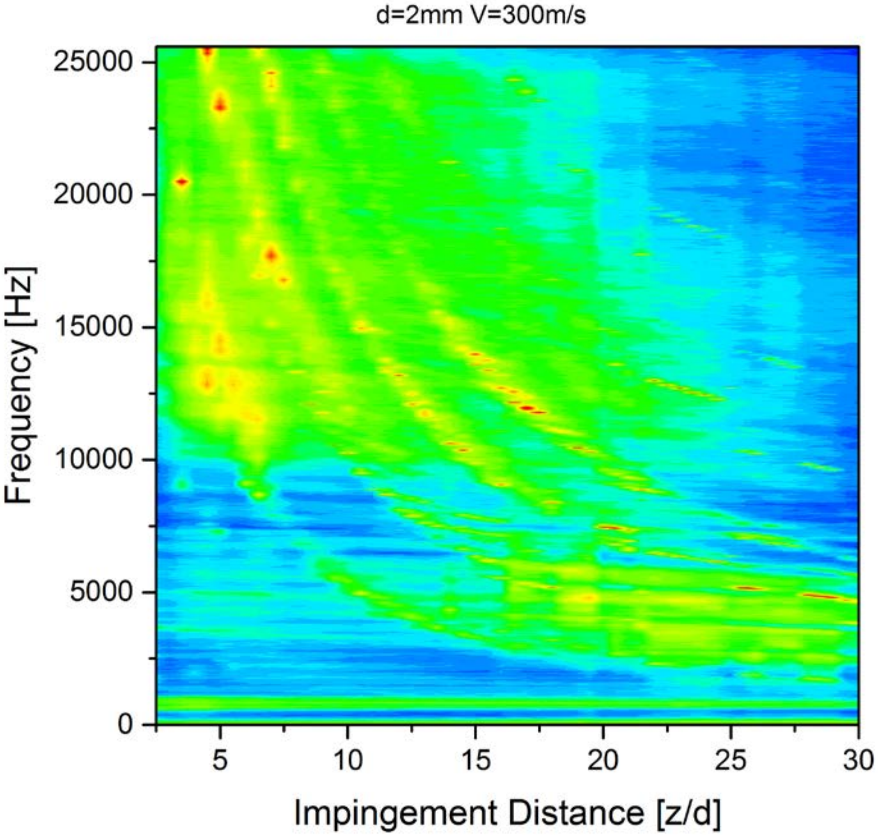


Main and Auxiliary Jets
(Confined)

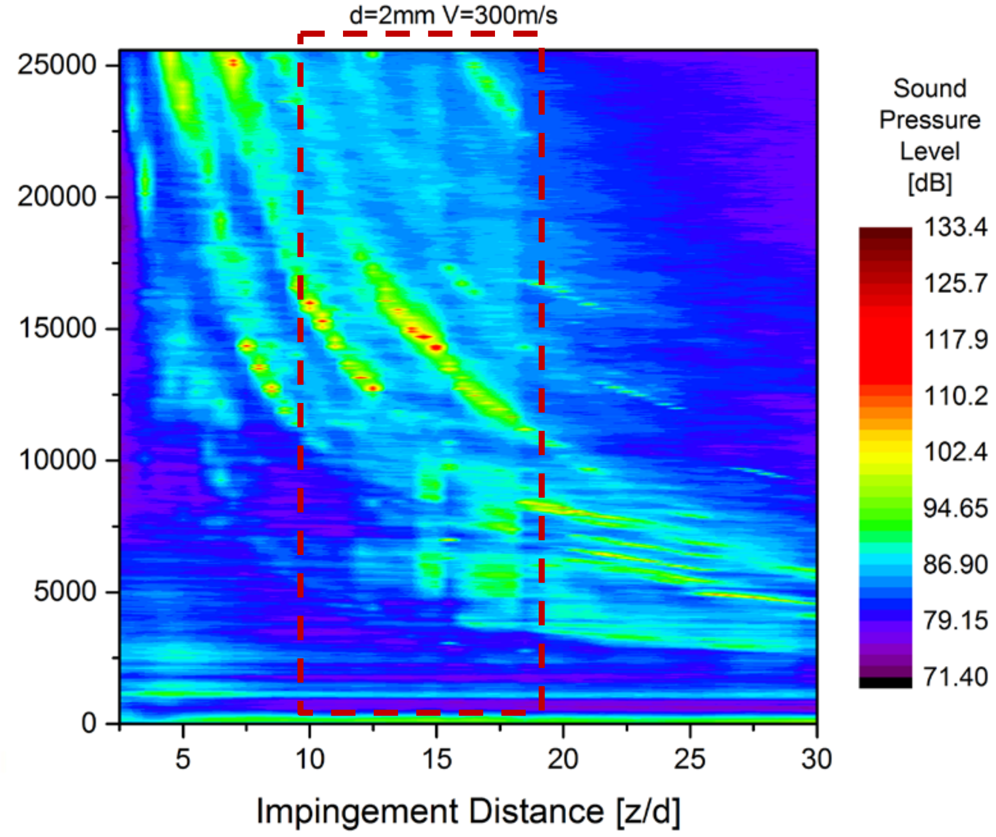


Confinement Effects for Shortened Nozzle

Unconfined Jet



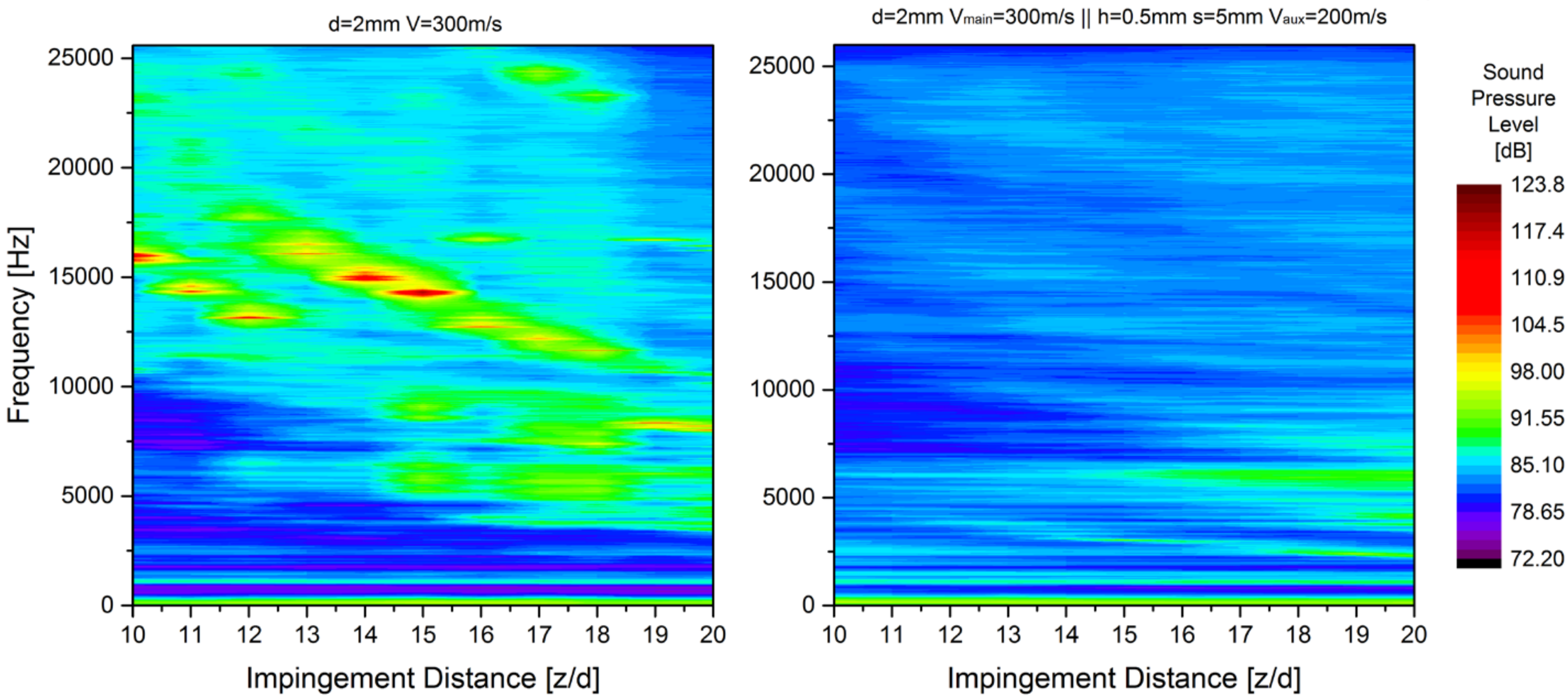
Confined Jet



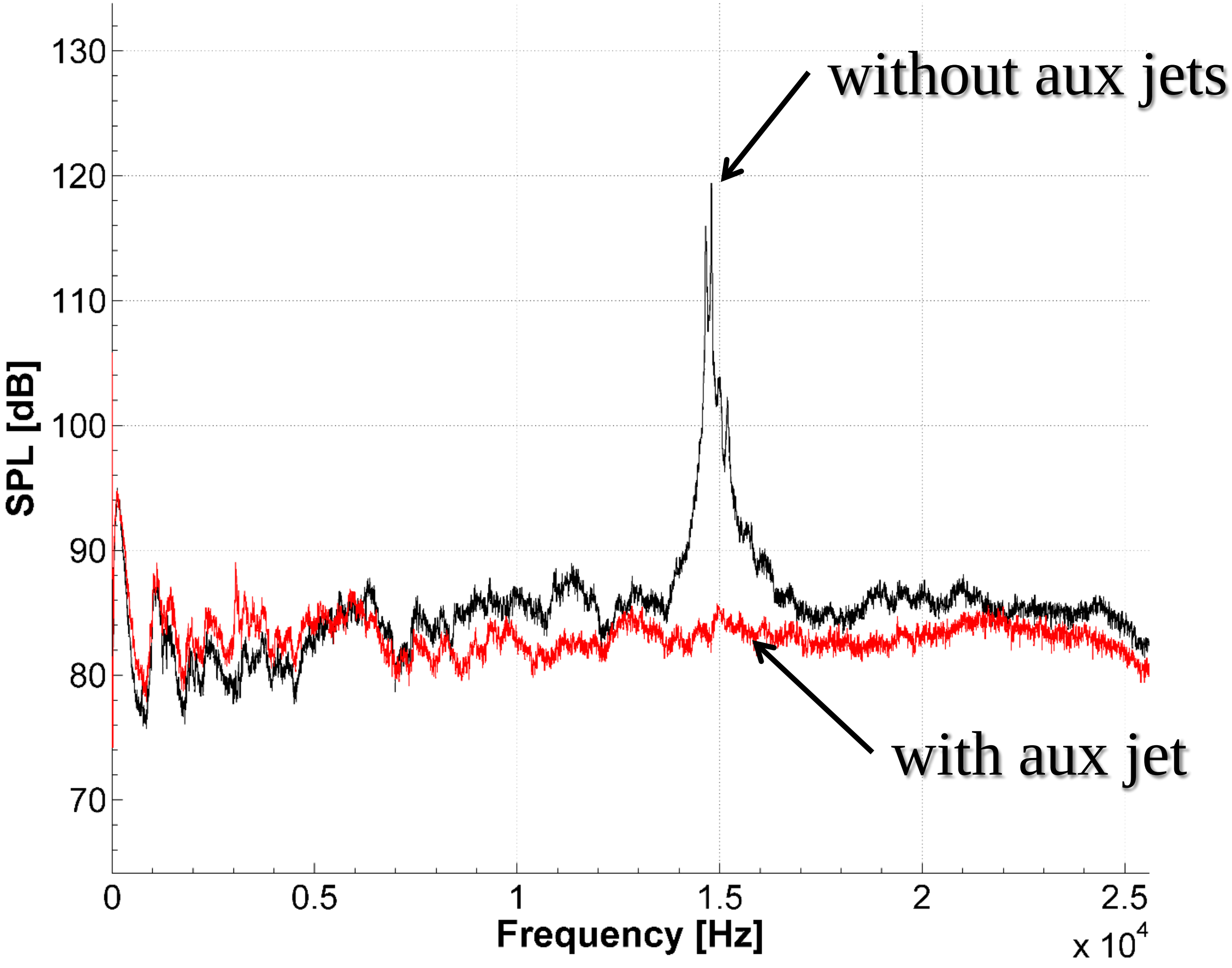
Effect of Auxiliary Jets on Noise

Auxiliary Jet OFF

Auxiliary Jet ON



Effect of Auxiliary Jets on Noise



V_{MAIN} = 300m/s

V_{AUX} = 200m/s

d = 2mm

h = 0.5mm

s = 5mm

z/d = 14

Task 5 – Summary

- **Measurement system verified**
- **Slight modification to long main nozzle required to produce similar noise spectra and intensity as previous work of Arthurs**
  - **trimmed 3mm off of main jet**
  - **essentially stiffened exit lips slightly**
- **Slight confinement effect of multi-jet design on main jet tones and intensity**
  - **sharp, high dB tones continue to be present**

Task 5 – Summary

- **Auxiliary jets have been shown to have a profound effect on noise reduction for parameters explored**
  - **confinement effect of auxiliary jets on main jet**
  - **consistent with effects of auxiliary jets on (dP/dx)max values at higher *z/d* from Alibeigi**

Task 5 – Future Work

- **Expand experimental matrix on noise measurements to various values of P(plenum), d, s/d and other geometric parameters**
- **Conduct PIV work – analytically investigate effect of auxiliary jets on main jet flapping**
  - **provide analytical and empirical models of effects on jet noise**