KTH ROYAL INSTITUTE
OF TECHNOLOGY

On Gas Dynamics of Exhaust Valves

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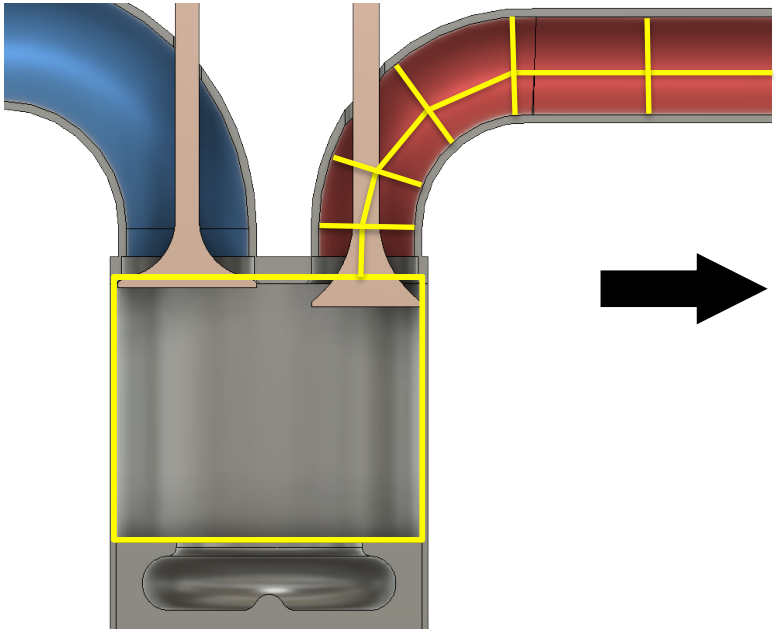
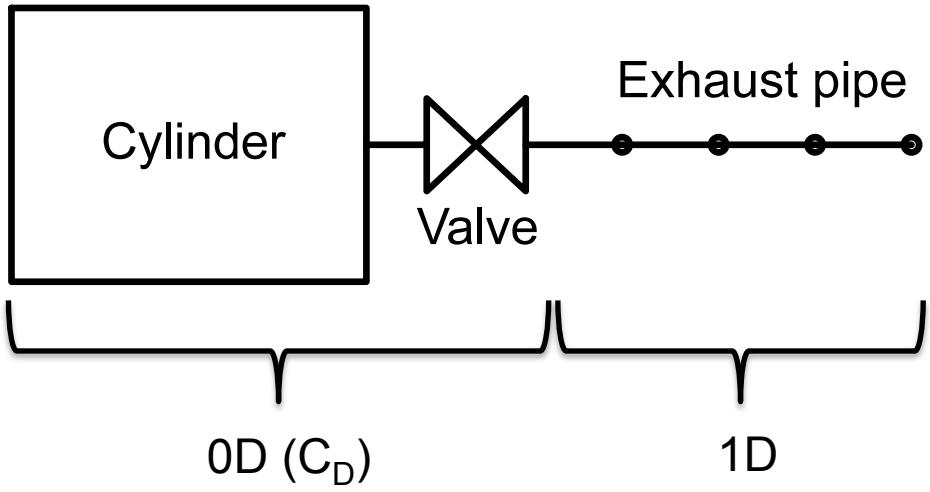
07.09.2017, CCGEx – Research Day

1D/0D simulations





$$C_D = \frac{\dot{m}_{actual}}{\dot{m}_{ideal}}$$

Measurements of C_D today assume:

- Static valve (quasi-steady)
- Low pressure ratios (insensitive to pressure ratio)

Objectives

Experimentally investigate the effects on C_D due to:

- Engine speed (valve opening time)
- Pressure ratio

Ideal mass flow

$$C_D = \frac{\dot{m}_{actual}}{\dot{m}_{ideal}}$$

Subcritical:

$$\dot{m}_{ideal} = \frac{A_T p_0}{\sqrt{RT_0}} \left(\frac{p_T}{p_0}\right)^{\frac{1}{\gamma}} \left\{ \frac{2\gamma}{\gamma - 1} \left[1 - \left(\frac{p_T}{p_0}\right)^{\frac{\gamma-1}{\gamma}} \right] \right\}^{\frac{1}{2}}$$

Choked:

$$\dot{m}_{ideal} = A_T p_0 \sqrt{\frac{\gamma}{RT_0}} \left(\frac{2}{\gamma+1}\right)^{(\gamma+1)/[2(\gamma-1)]}$$

A_T - Throat area

p_T - Throat pressure

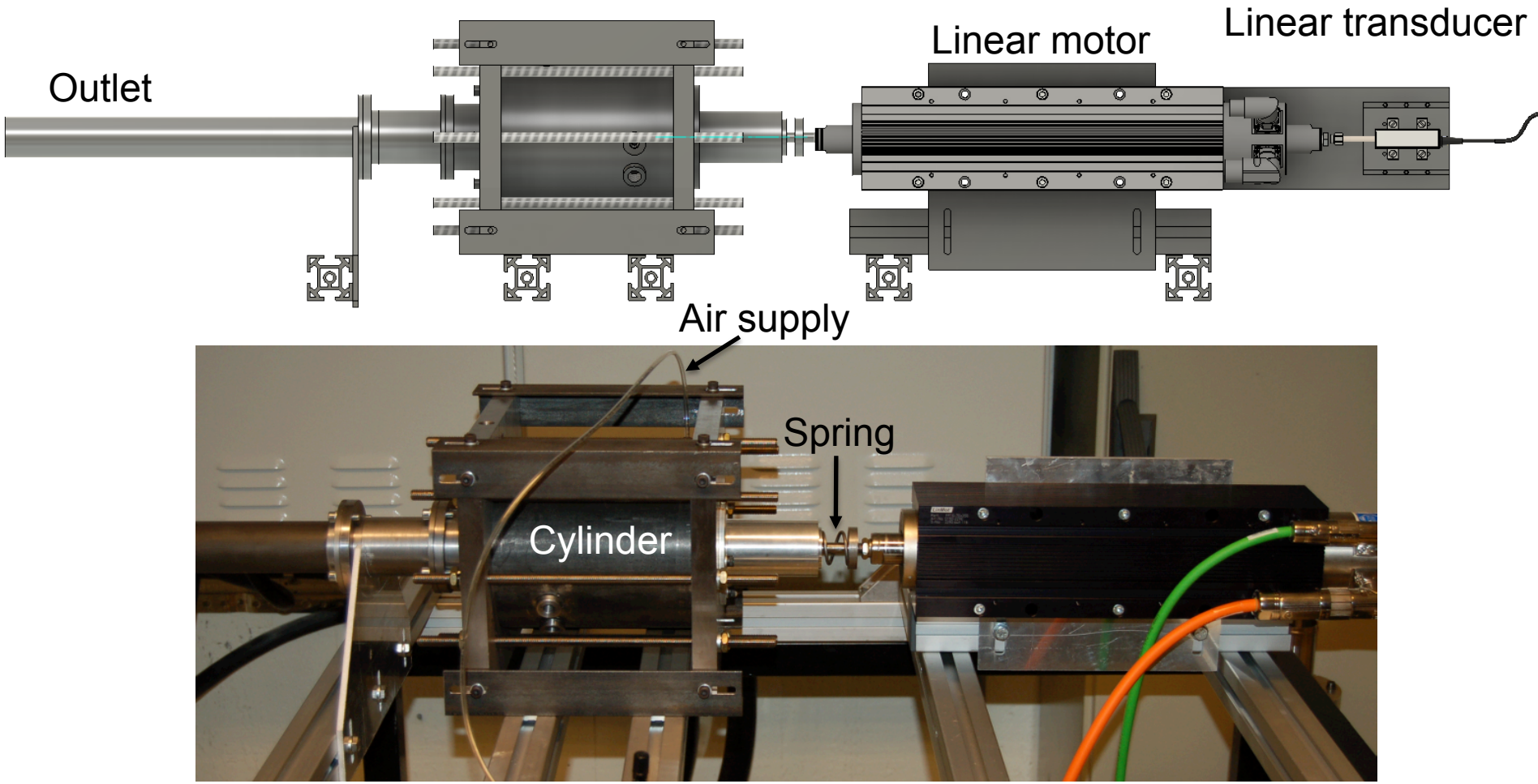
p_0 - Total pressure

T_0 - Total temperature

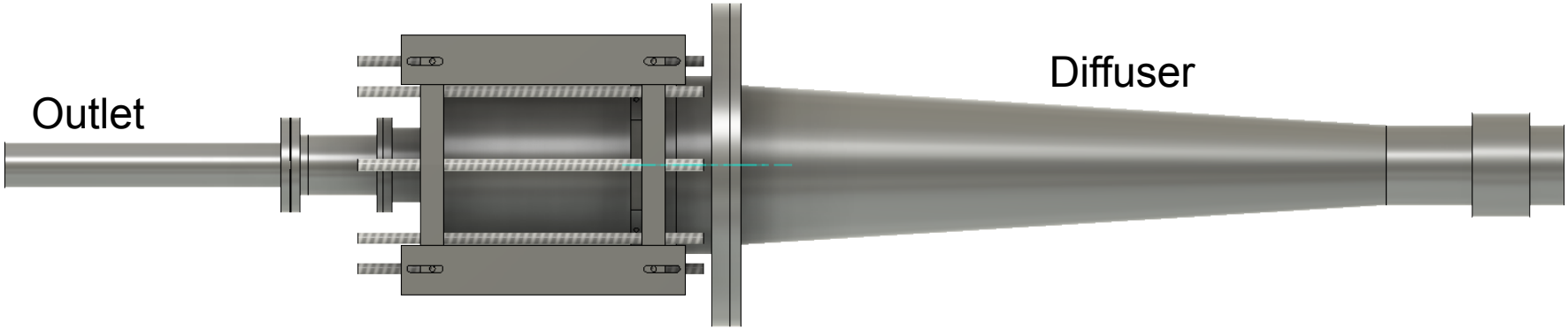
γ - Ratio of specific heats

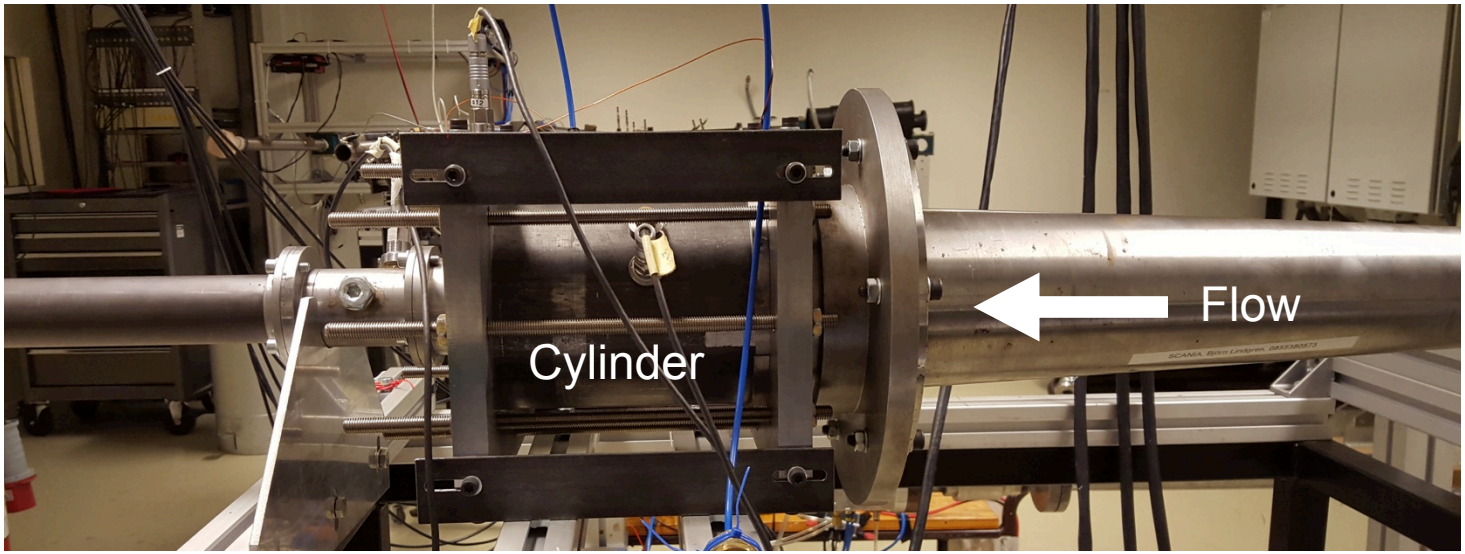
R - Specific gas constant

Dynamic valve setup



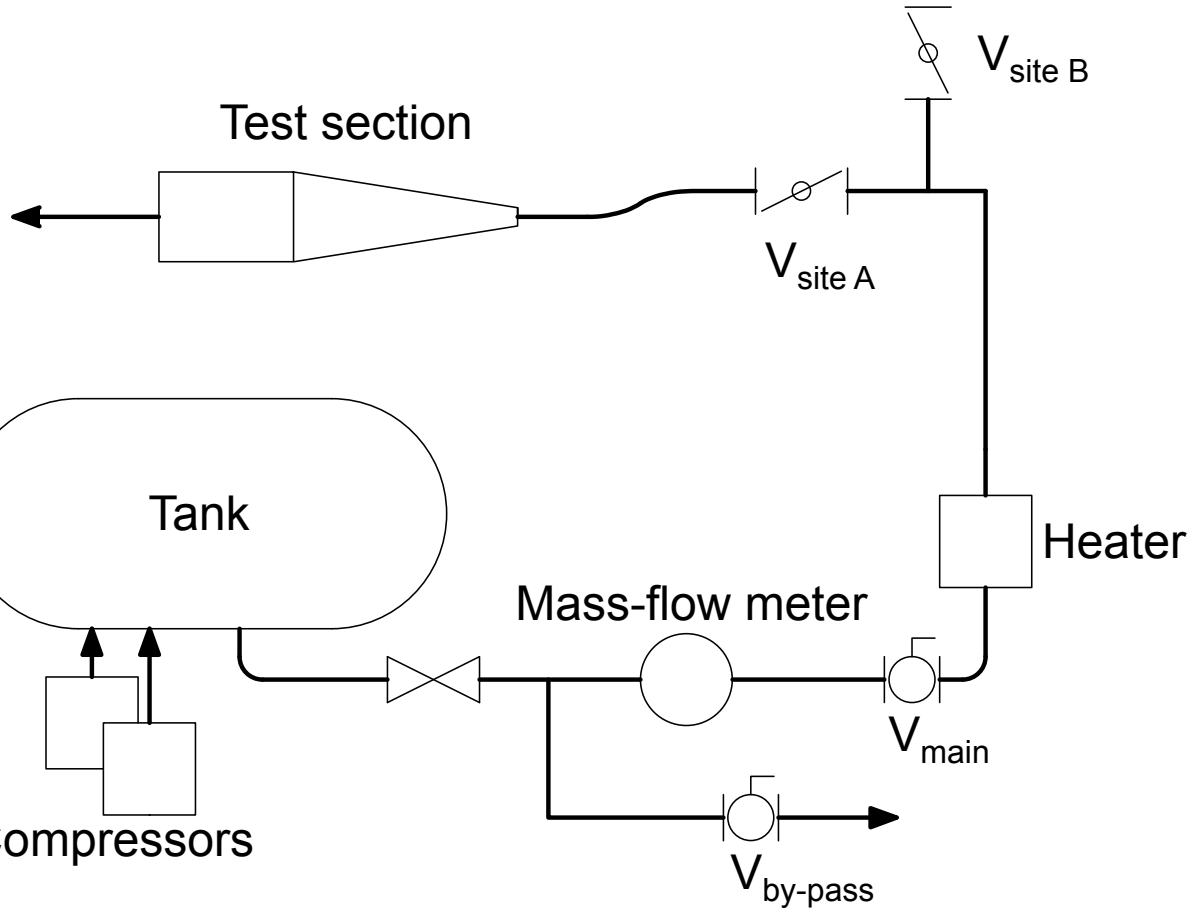
Static valve setup





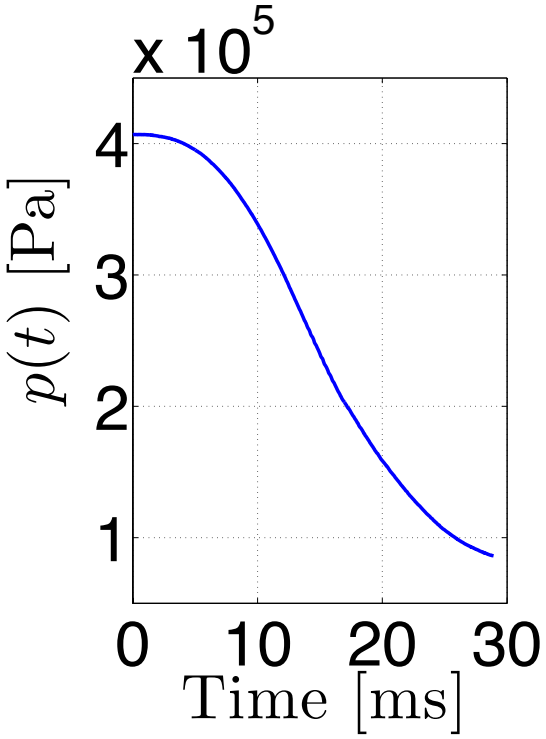
CICERO Laboratory

$$\dot{m}_{max} = 0.5 \text{ kg/s}$$
$$p_{max} = 500 \text{ kPa}$$



Time-resolved mass flow

$$m(t) = \frac{V}{R}\frac{p(t)}{T(t)}$$



Expansion in the cylinder may be viewed as isentropic

$$\frac{p_2}{p_1} = \left(\frac{T_2}{T_1}\right)^{\gamma/(\gamma-1)}$$

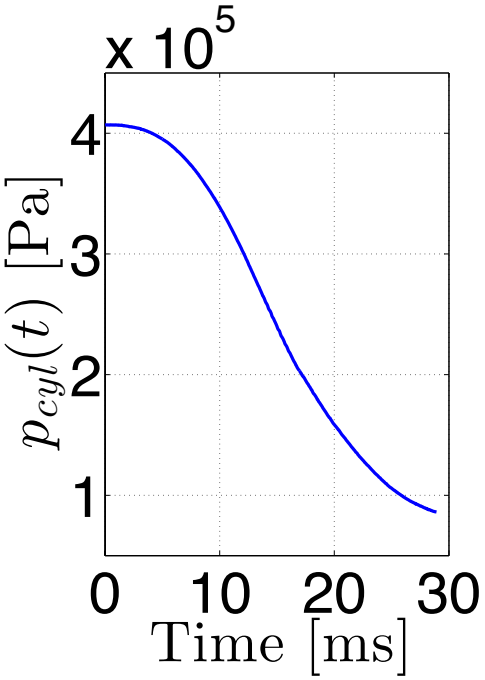
Meaning the mass in the cylinder is a function of the pressure and initial temperature

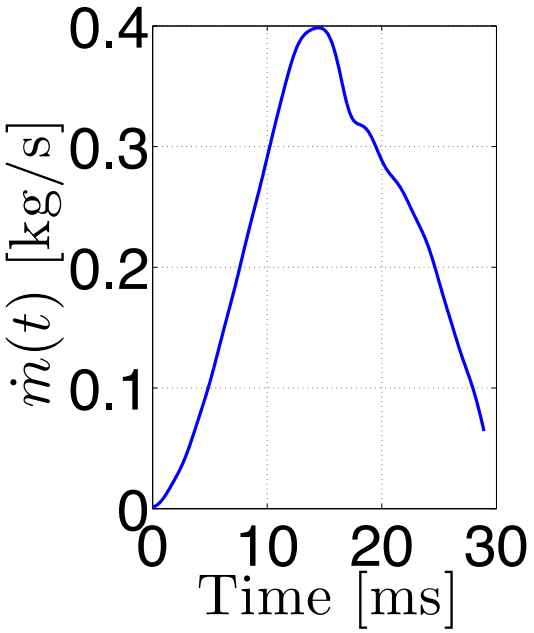
$$m(t) = f\big(p(t), T(t=0)\big)$$

Time-resolved mass flow

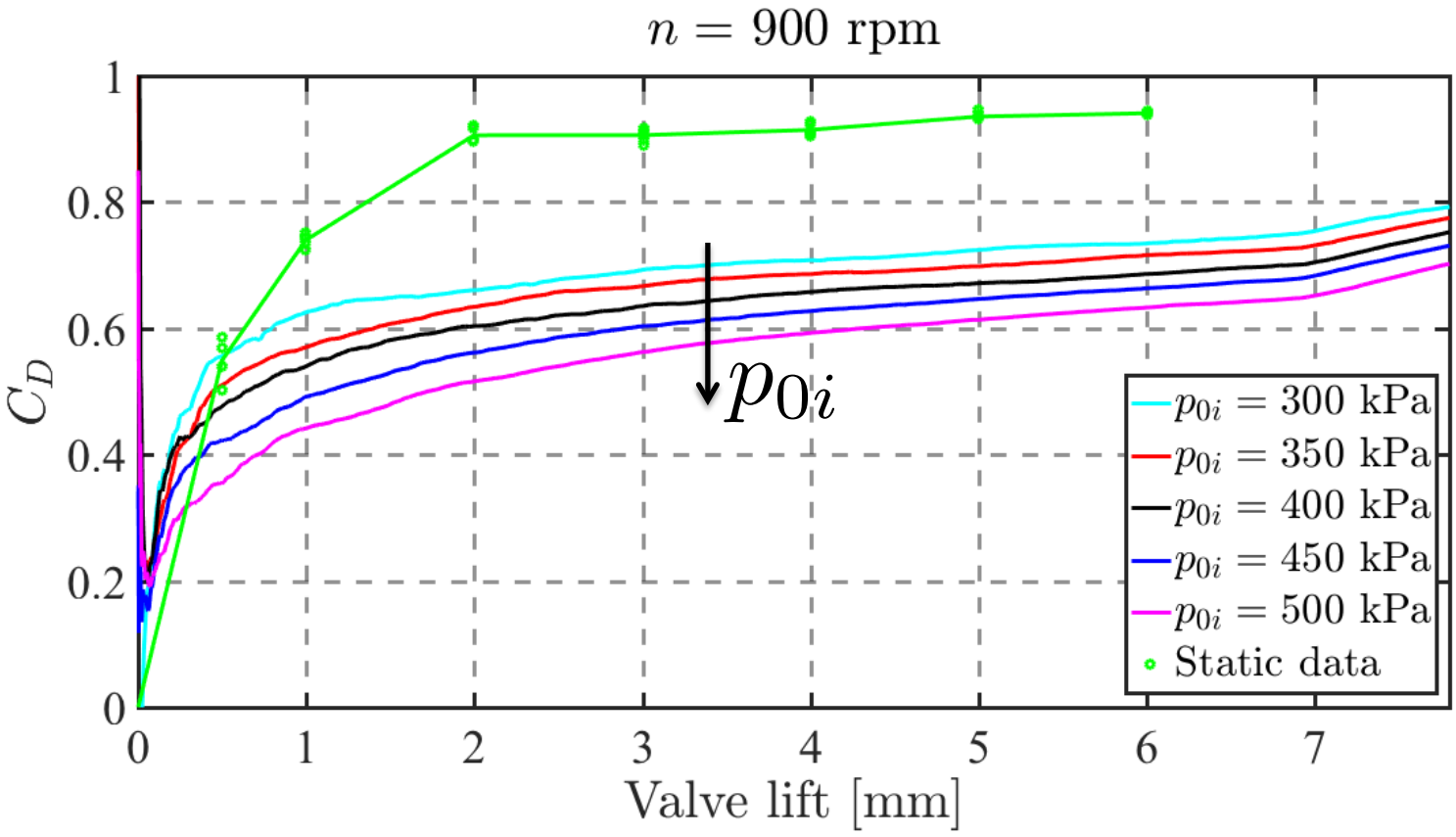
$$\dot{m} = \frac{dm}{dt} = \frac{V}{\gamma R T_{0_i}} \left(\frac{p_{0_i}}{p} \right)^{(\gamma-1)/\gamma} \frac{dp}{dt}$$

$$n = 900 \text{ rpm}$$
$$p_{0_i} = 400 \text{ kPa}$$

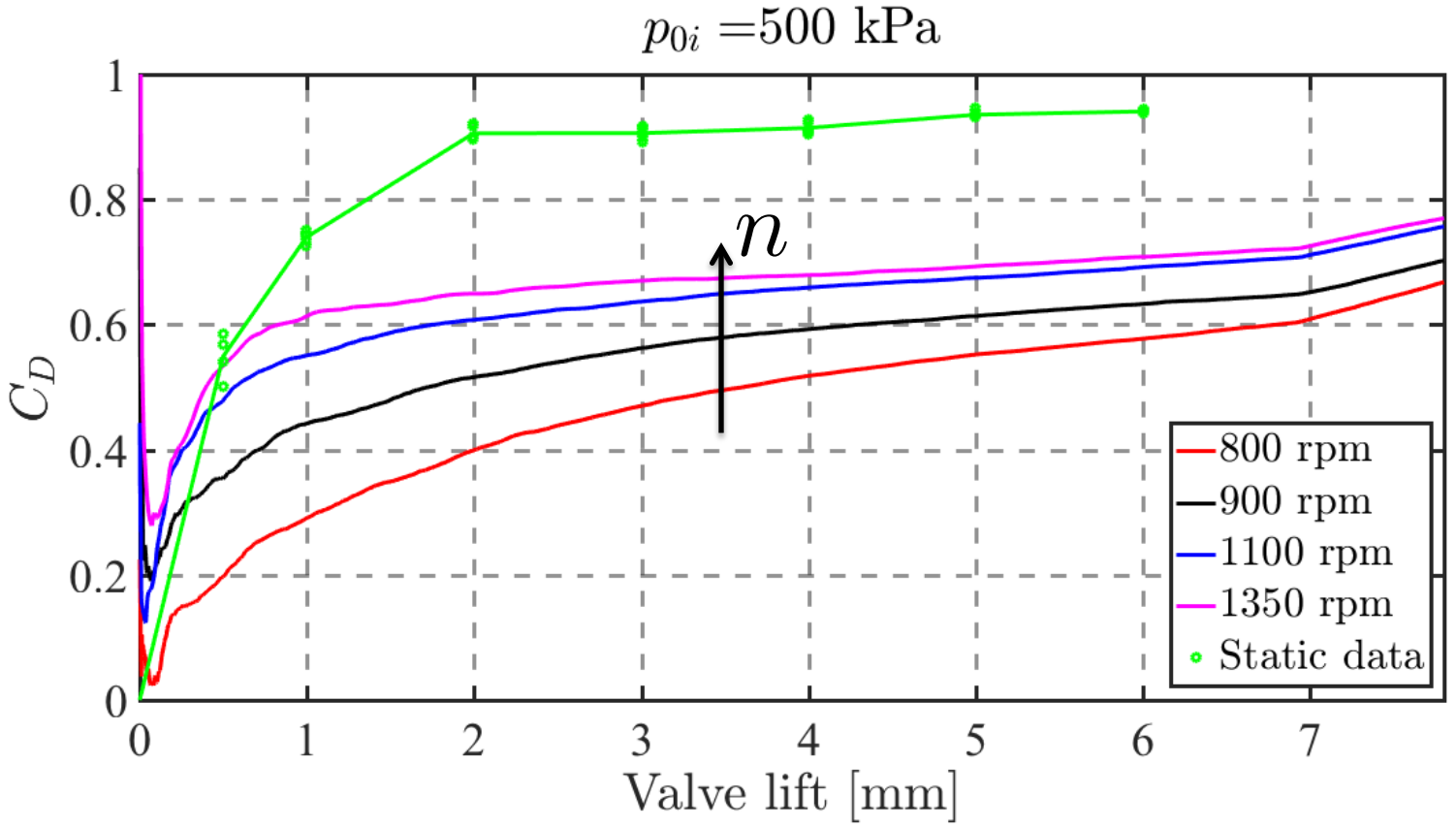




Initial pressure



Engine speed



Quasi-steadiness

$$u_{geometry} << u_{flow}$$

$$\tau_{geometry} >> \tau_{flow} \Rightarrow \text{Quasi-steady}$$

Classical idea

Quasi-steadiness

$$u_{geometry} << u_{flow}$$

$$\tau_{geometry} >> \tau_{flow} \Rightarrow \text{Quasi-steady}$$

Classical idea

Neglects the dynamics of the flow conditions

$$\tau_{condition} >> \tau_{geometry} >> \tau_{flow} \Rightarrow \text{Quasi-steady}$$

A measure of quasi-steadiness

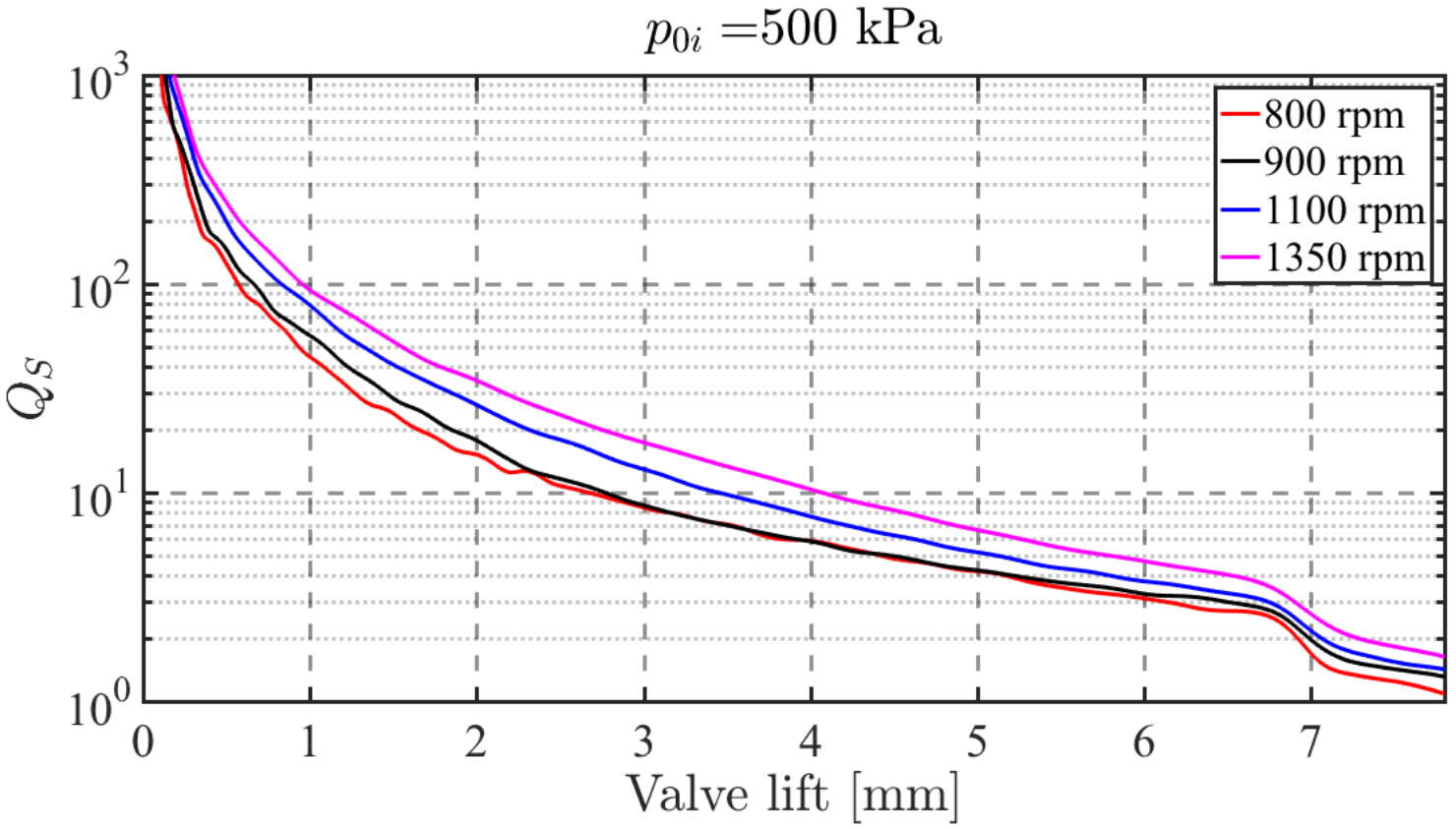
$$Q_S = \frac{\dot{A}_T / A_T}{\dot{m}/m}$$

$$Q_S = C \cdot \left(\frac{p_{0_i}}{p_0}\right)^{(\gamma-1)/2\gamma} \frac{V}{A_T \sqrt{\gamma R T_{0_i}}} \frac{\dot{A}_T}{A_T}$$

$$Q_S \gg 1 \Rightarrow \quad \text{Quasi-steady}$$

$$C = \left(\frac{\gamma+1}{2}\right)^{(\gamma+1)/[2(\gamma-1)]}$$

A measure of quasi-steadiness



Conclusions

It has been shown that:

- The assumptions of quasi-steadiness and pressure-ratio independence do not hold
  - C_D decreases with initial pressure
  - C_D increases with engine speed

Reference:

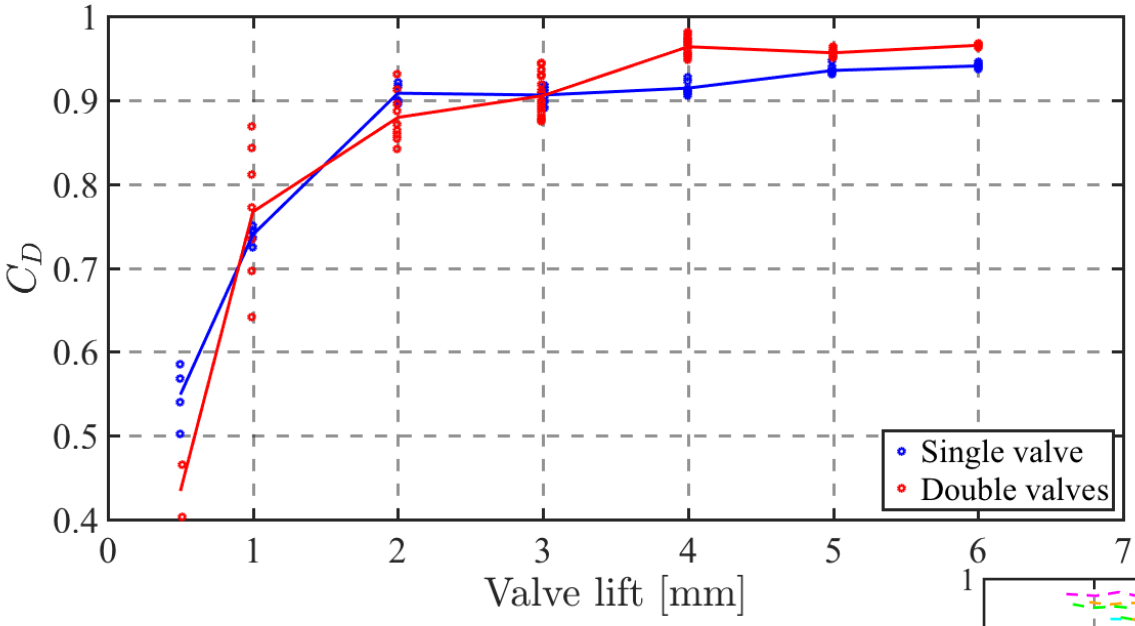
M Winroth (2017) “On Gas Dynamics of Exhaust Valves”. Licentiate Thesis, KTH Mechanics, March 2017

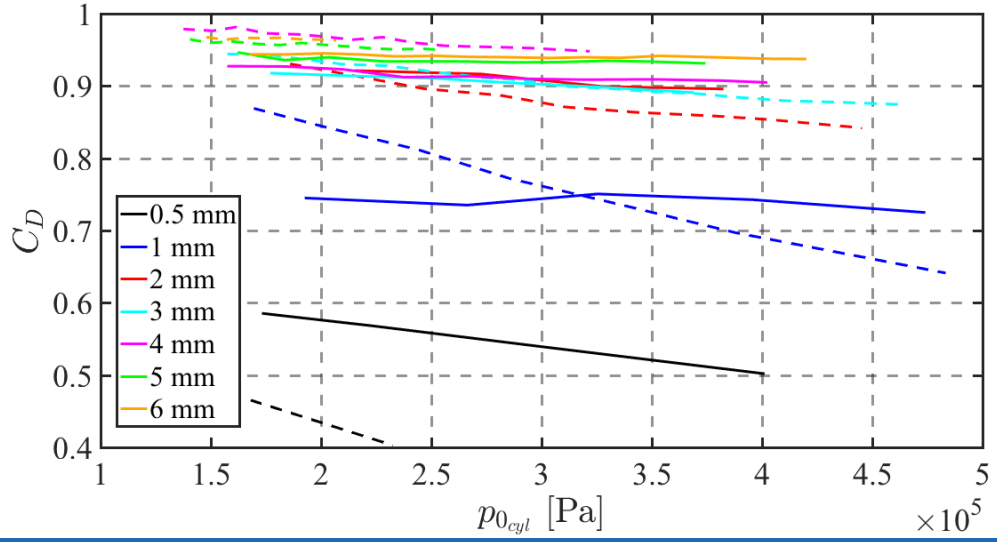
Competence Center for Gas Exchange

CC GEx

”Charging for the future”

Double-valve setup





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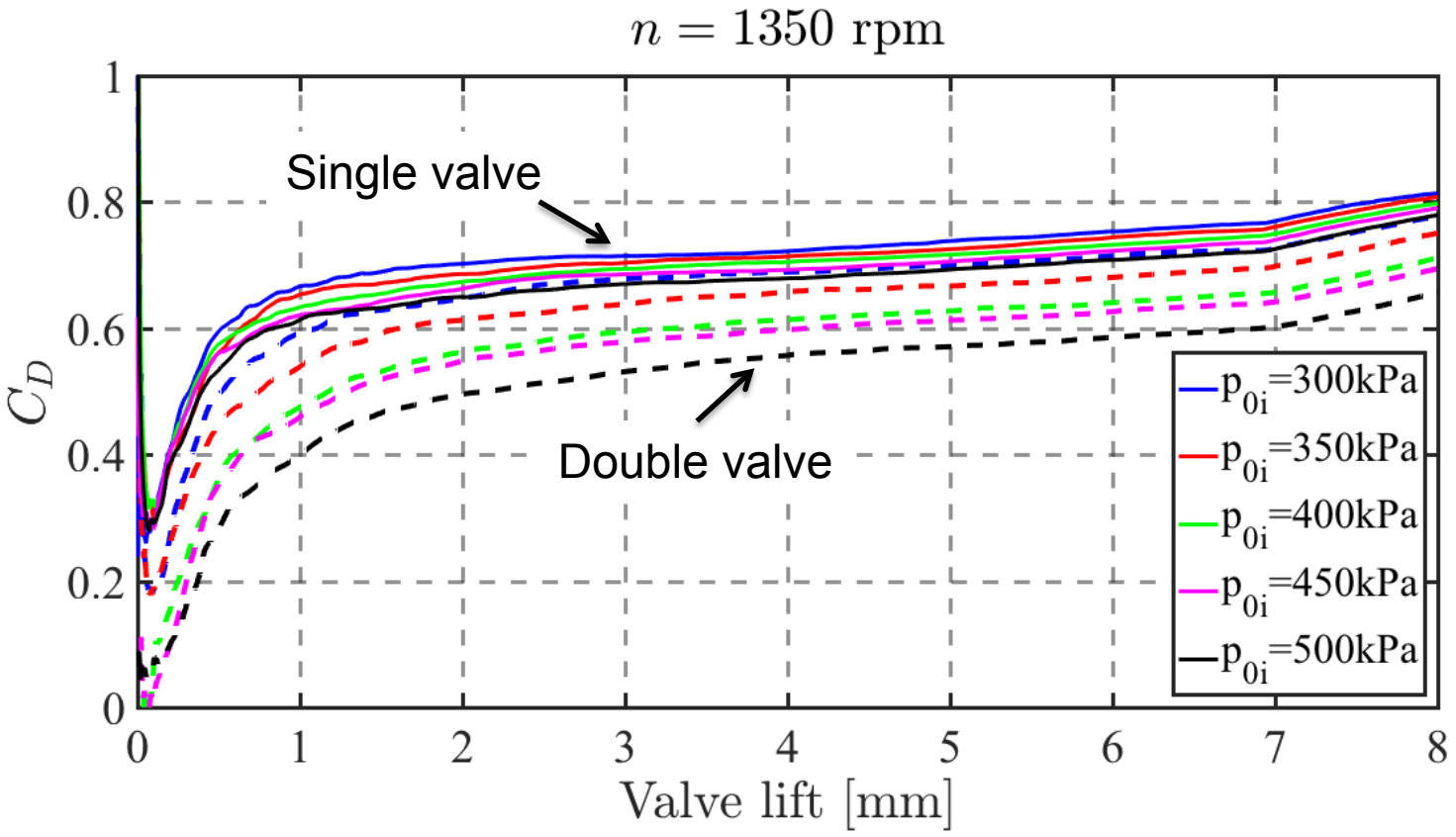
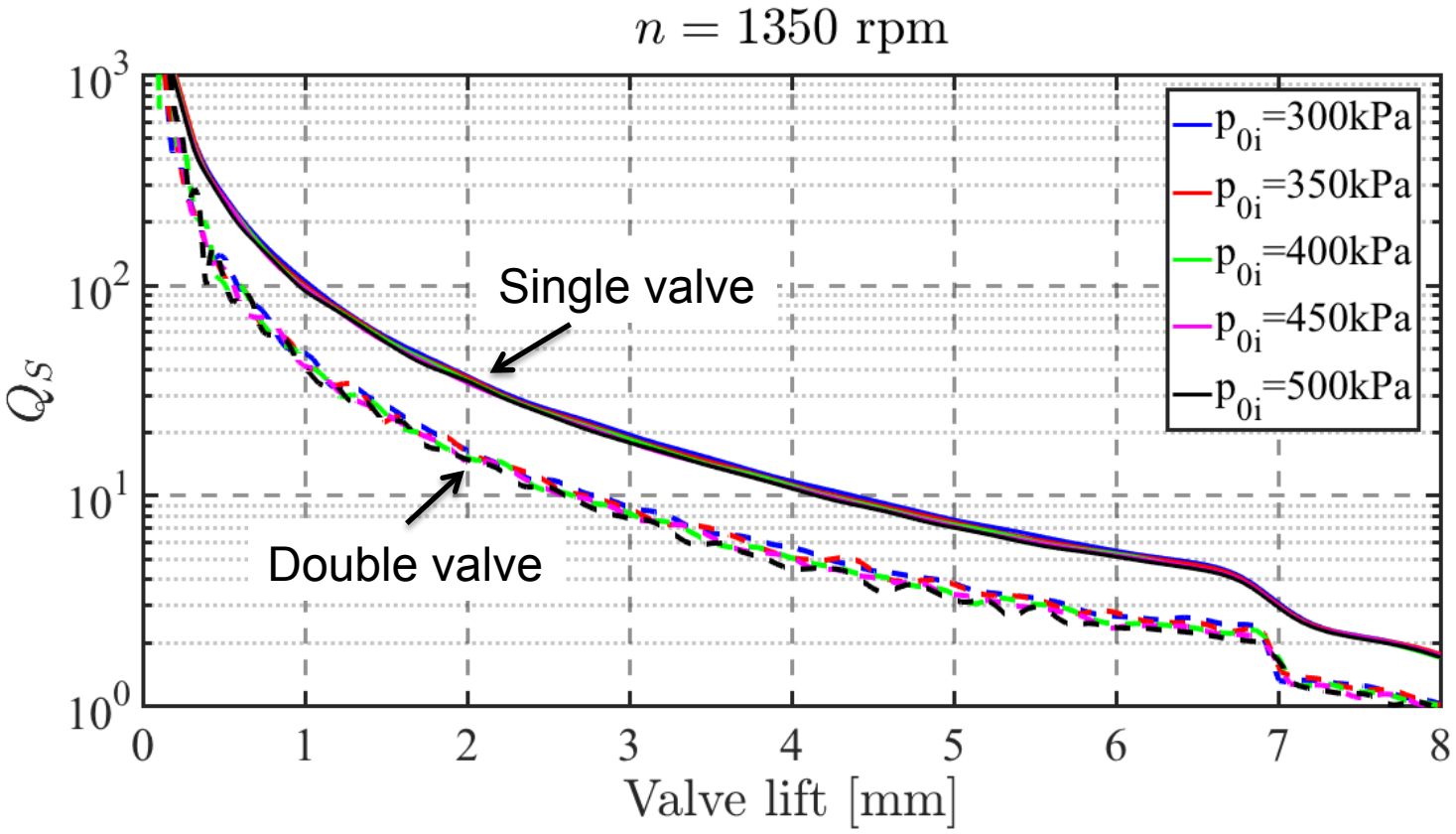
Double-valve setup