Gas Dynamics of Exhaust Valves

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Outline

- Background and objectives
- Experimental setup and techniques
- Early results and conclusions

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Background

- Semi empirical 1D models used for optimization of engine system
- Discharge coefficient

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

- Measurements of C_D today:
  - Fixed valve lift (assuming quasi steady)
  - Low pressure ratios (assuming pressure ratio independence)
  - Typical experiments performed in industry have a maximum M ≈ 0.3 (incompressible)

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Objectives

Experimentally test the effects of:

- Quasi-steady valve assumption
- High pressure ratio
- Radial positioning of the valve
- Interaction of two valves
- Valve opening profiles
- Exhaust port geometry

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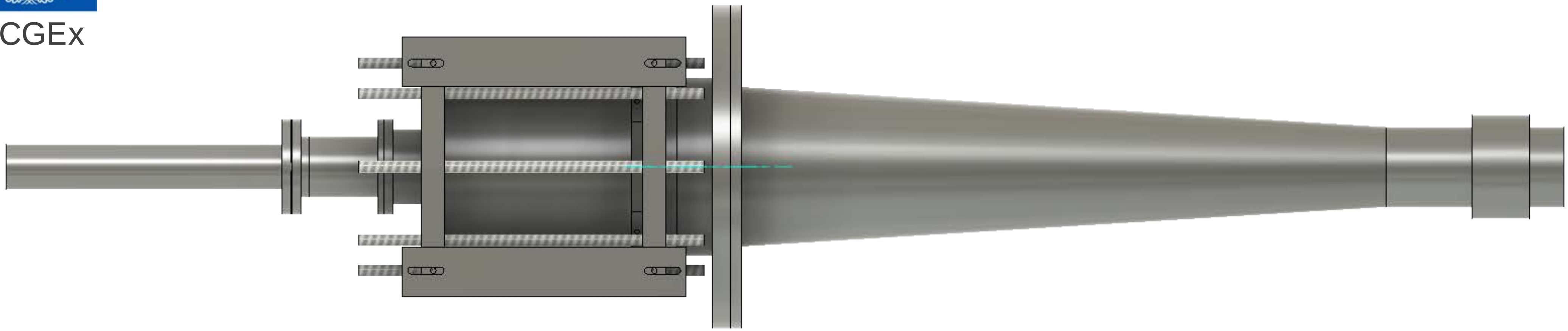
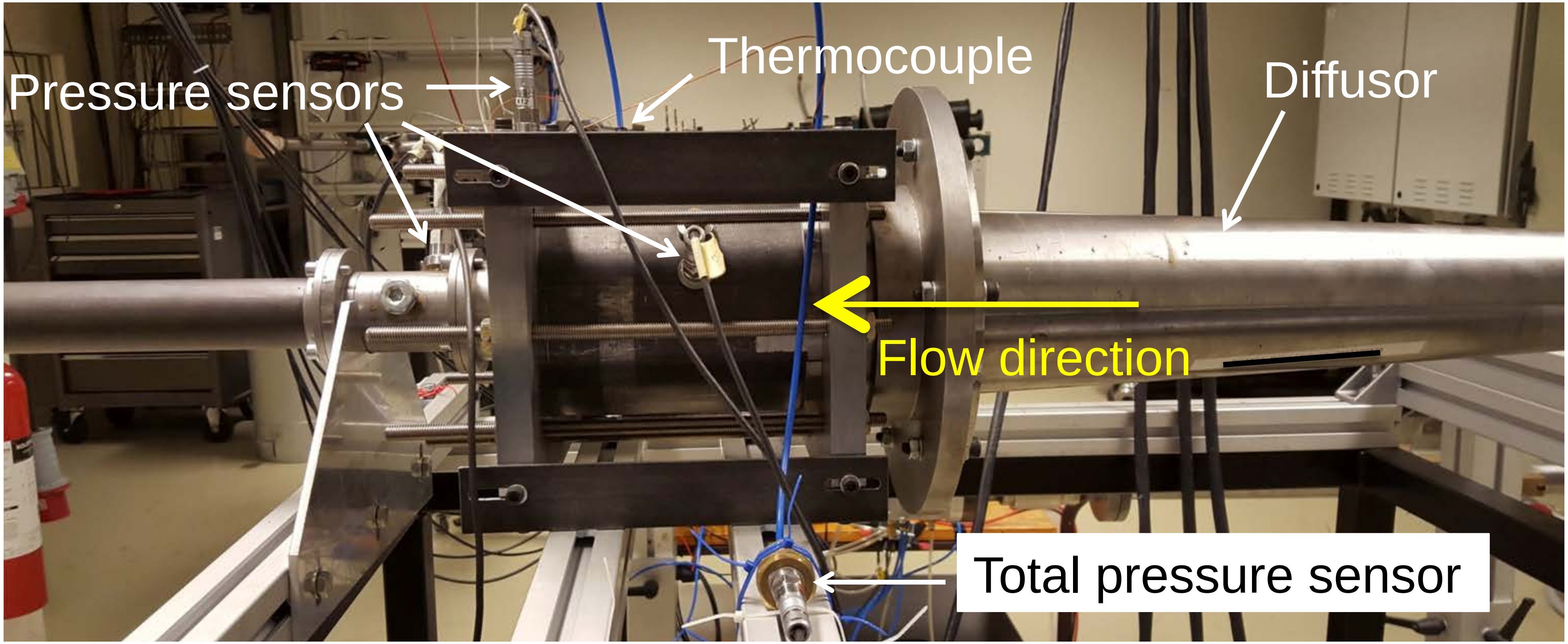
Static valve setup





Dynamic valve setup

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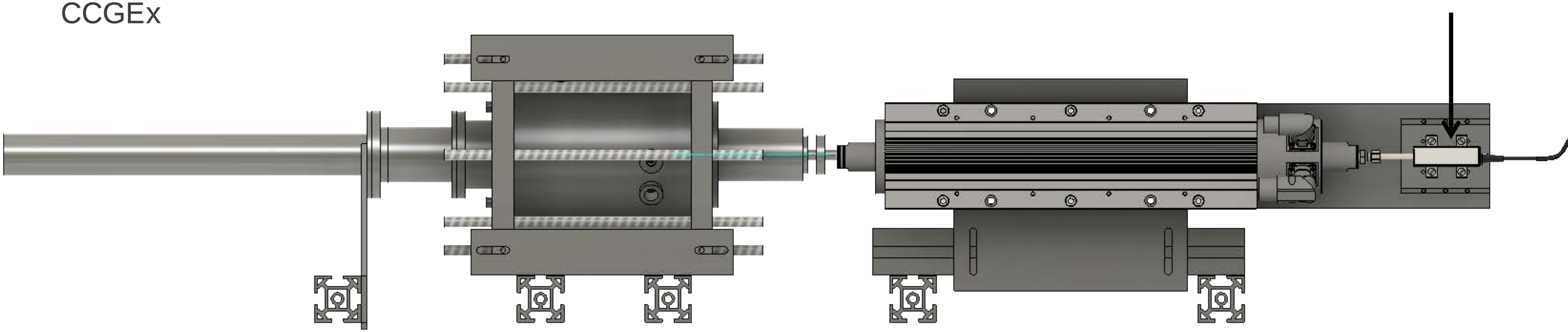
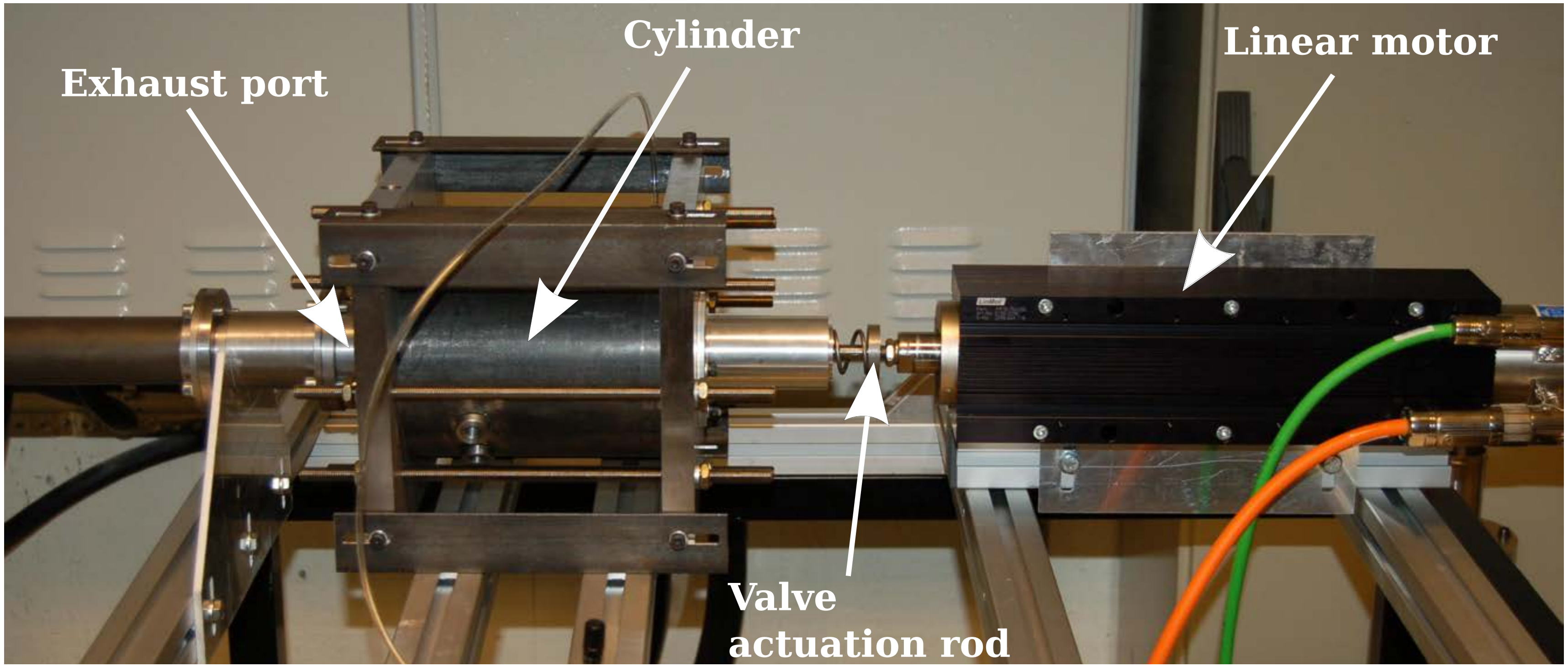
Linear transducer





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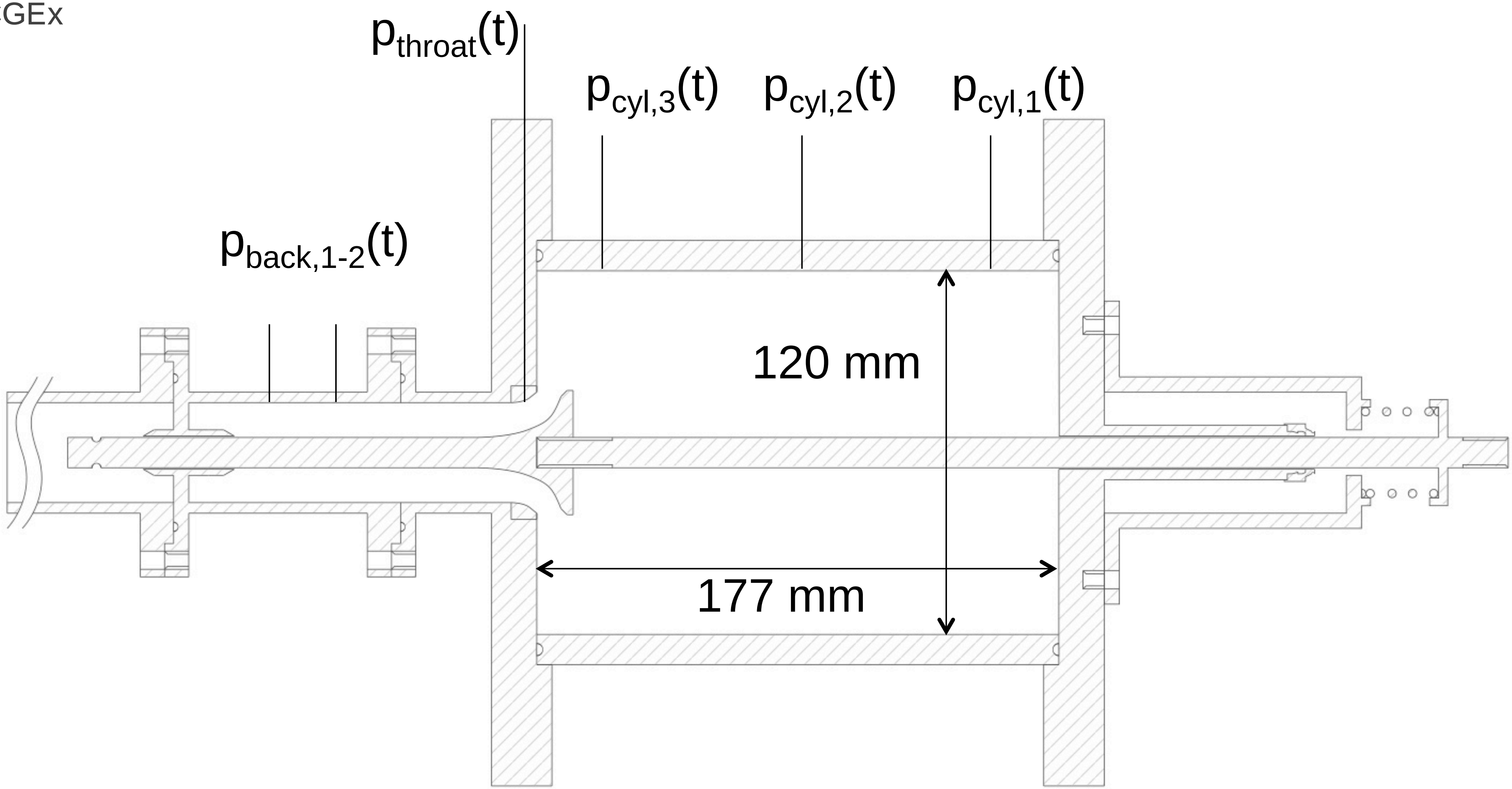
Dynamic valve setup



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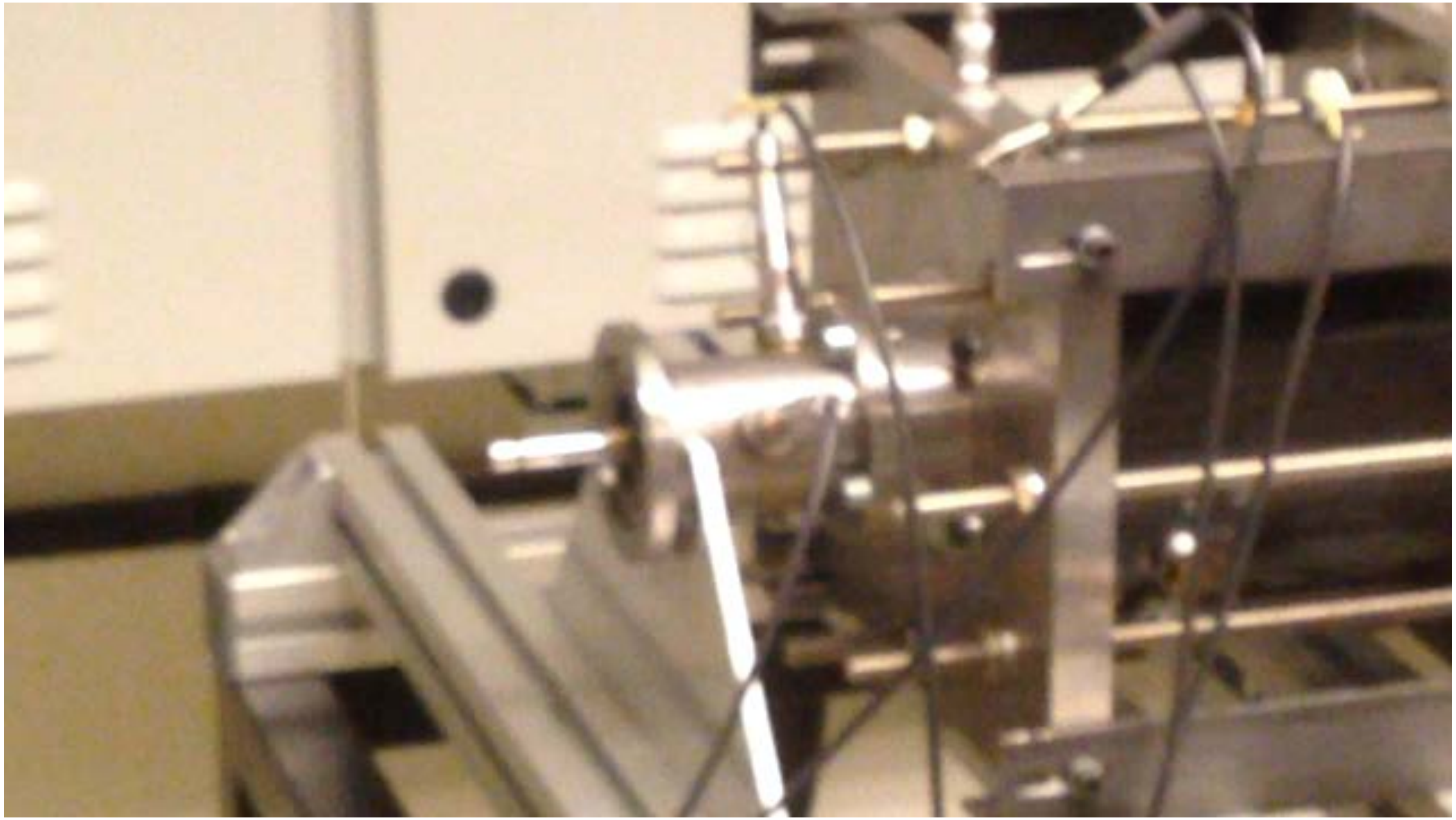
Dynamic valve setup



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C_D

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

Using the isentropic relations, the Mach number and conservation of mass flow gives for sub-critical flows:

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

$A_T - Throat\ area$

$p_T - Throat\ pressure$

$p_0 - Cylinder\ total\ pressure$

$\gamma - Ratio\ of\ specific\ heats$

$R - Specific\ gas\ constant$

C_D

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While for chocked conditions:

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

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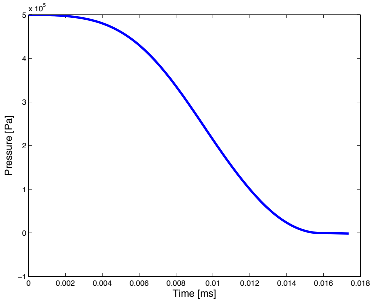
Time resolved mass flow

$p(t)$



t

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

The expansion in the cylinder may be viewed as isentropic, hence

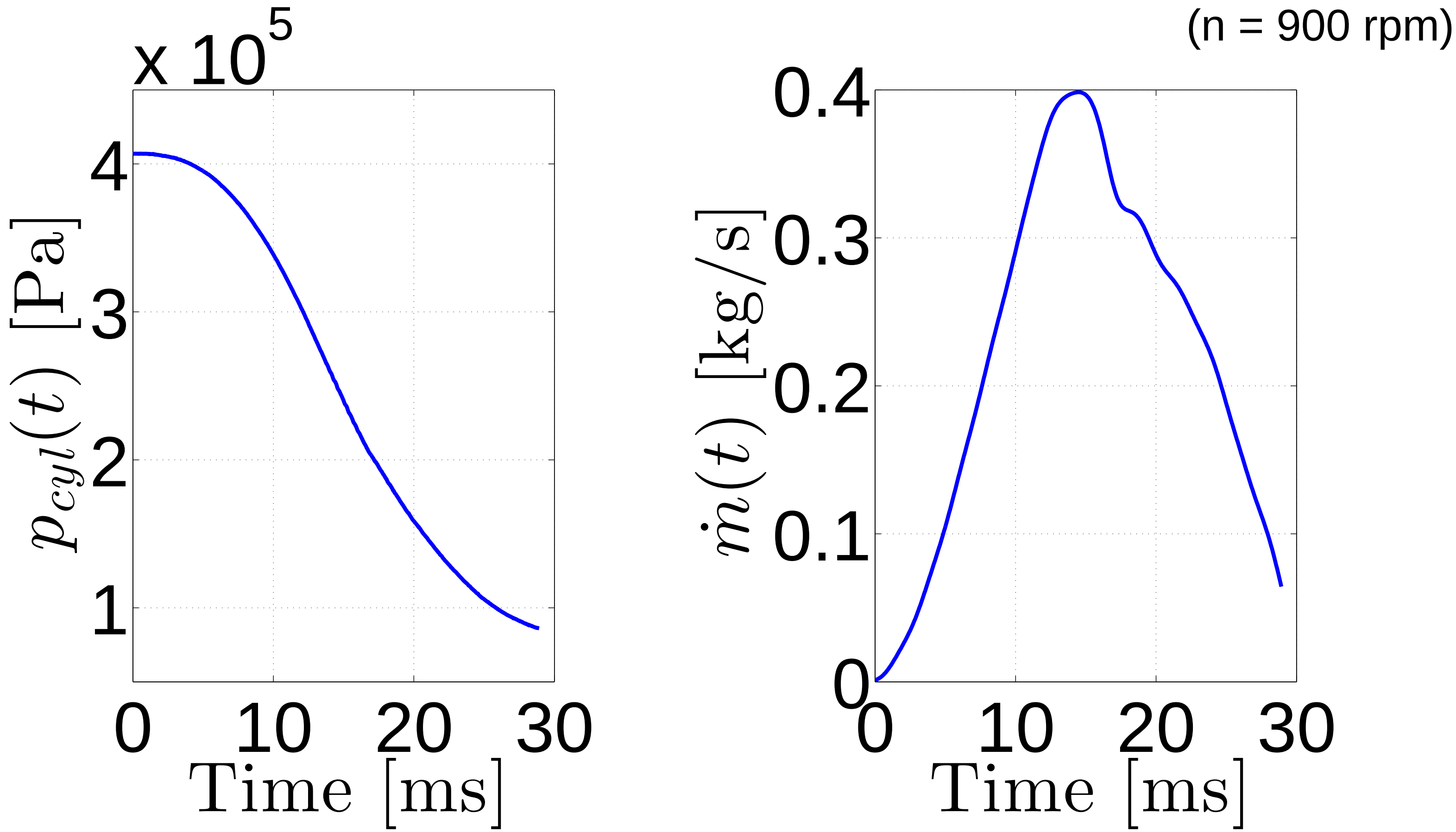
$$\frac{p}{p_0} = \left(\frac{T}{T_0}\right)^{\gamma/(\gamma-1)}$$

which gives

$$\frac{p}{T} = T_0^{-1} p_0^{(\gamma-1)/\gamma} p^{1/\gamma} = C p^{1/\gamma}$$

Meaning it is sufficient to measure *p(t)* and *T(t=0)* to obtain the mass flow.

Time resolved mass flow



$$\dot{m} = \frac{\mathrm{d}m}{\mathrm{d}t} = \frac{V}{\gamma R T_0} \left(\frac{p_0}{p} \right)^{(\gamma - 1)/\gamma} \frac{\mathrm{d}p}{\mathrm{d}t}$$

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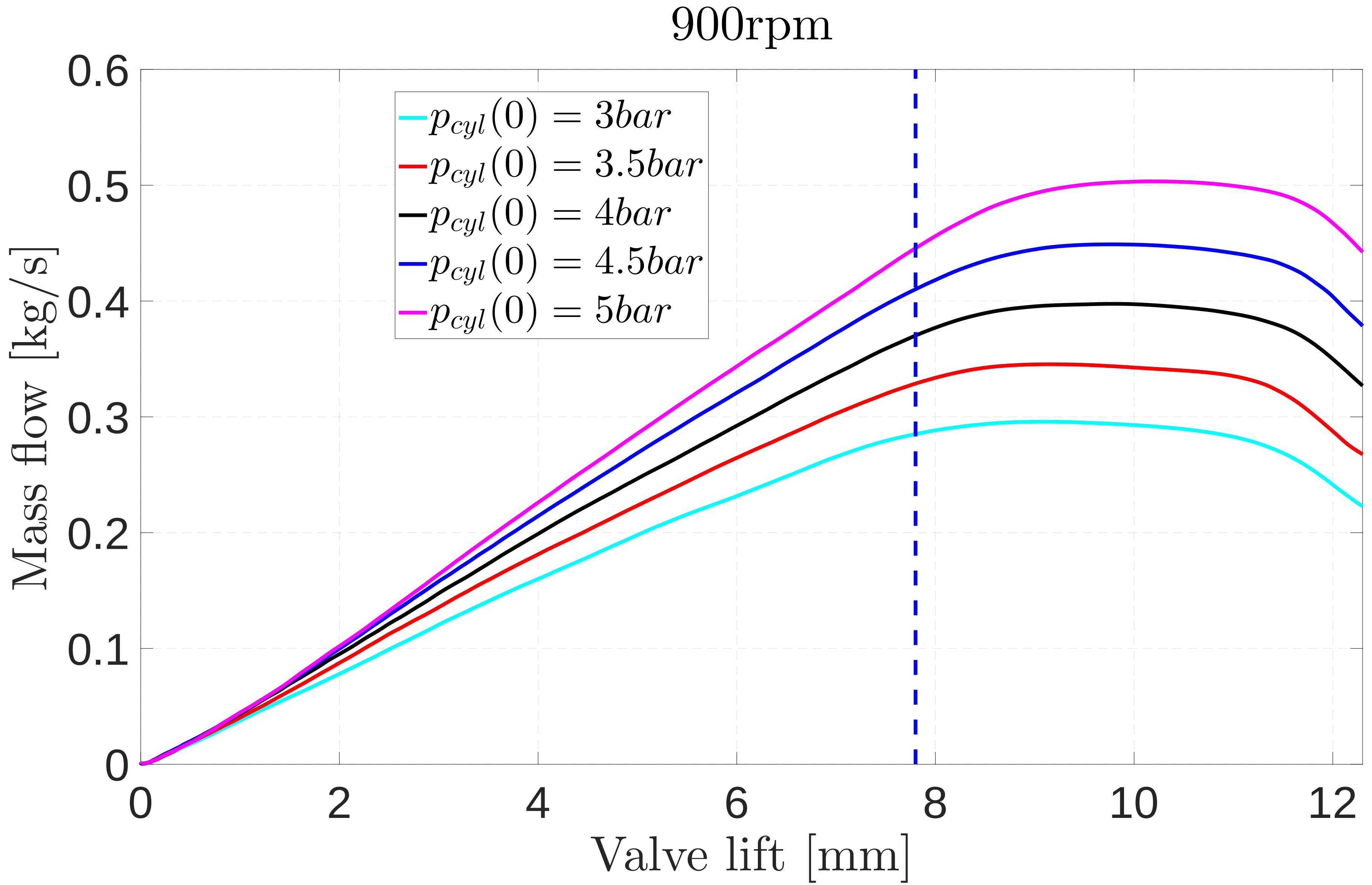
Mass flow @ 900 rpm



C_D @ 900 rpm

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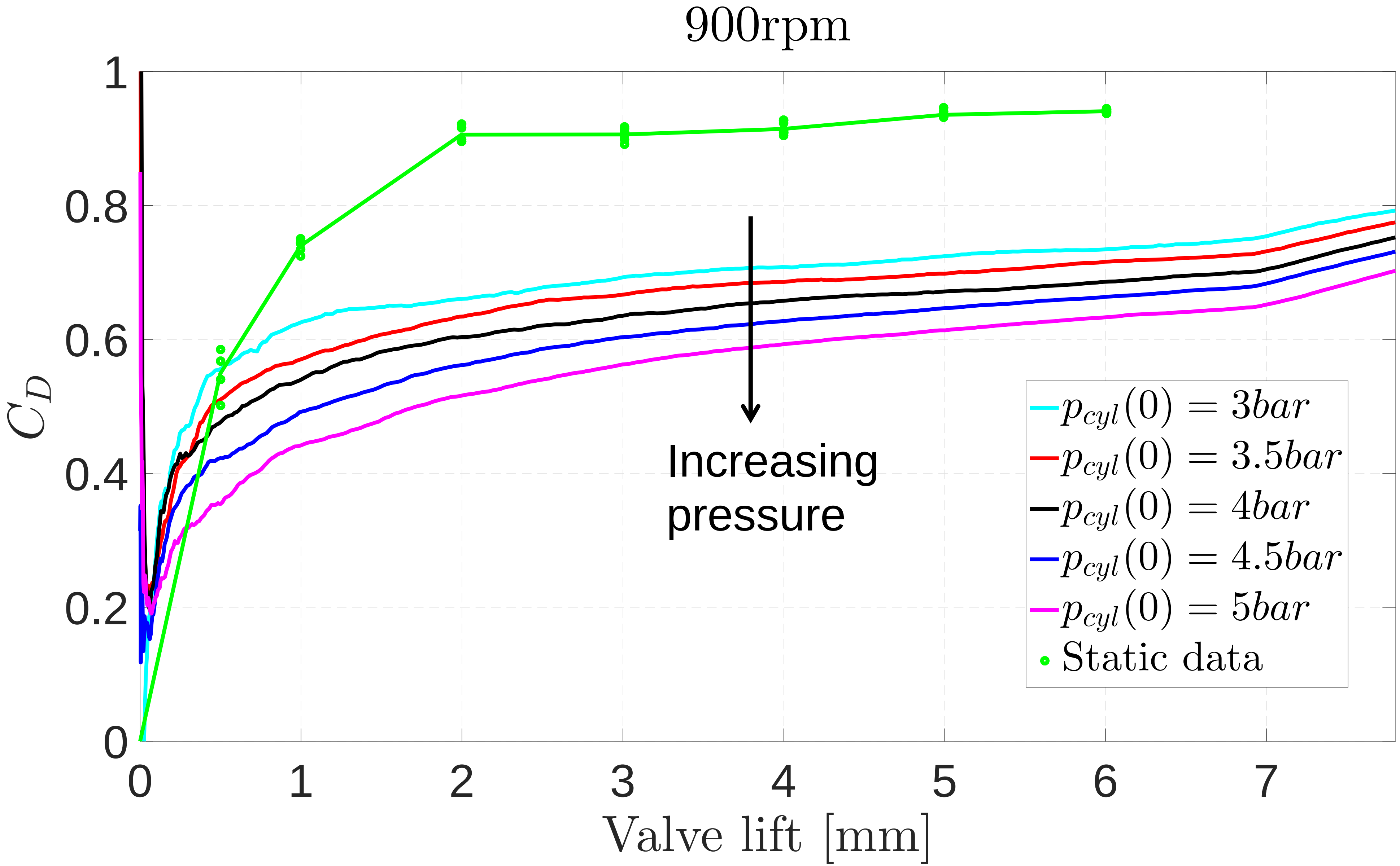

C_D @ p(0) = 5bar

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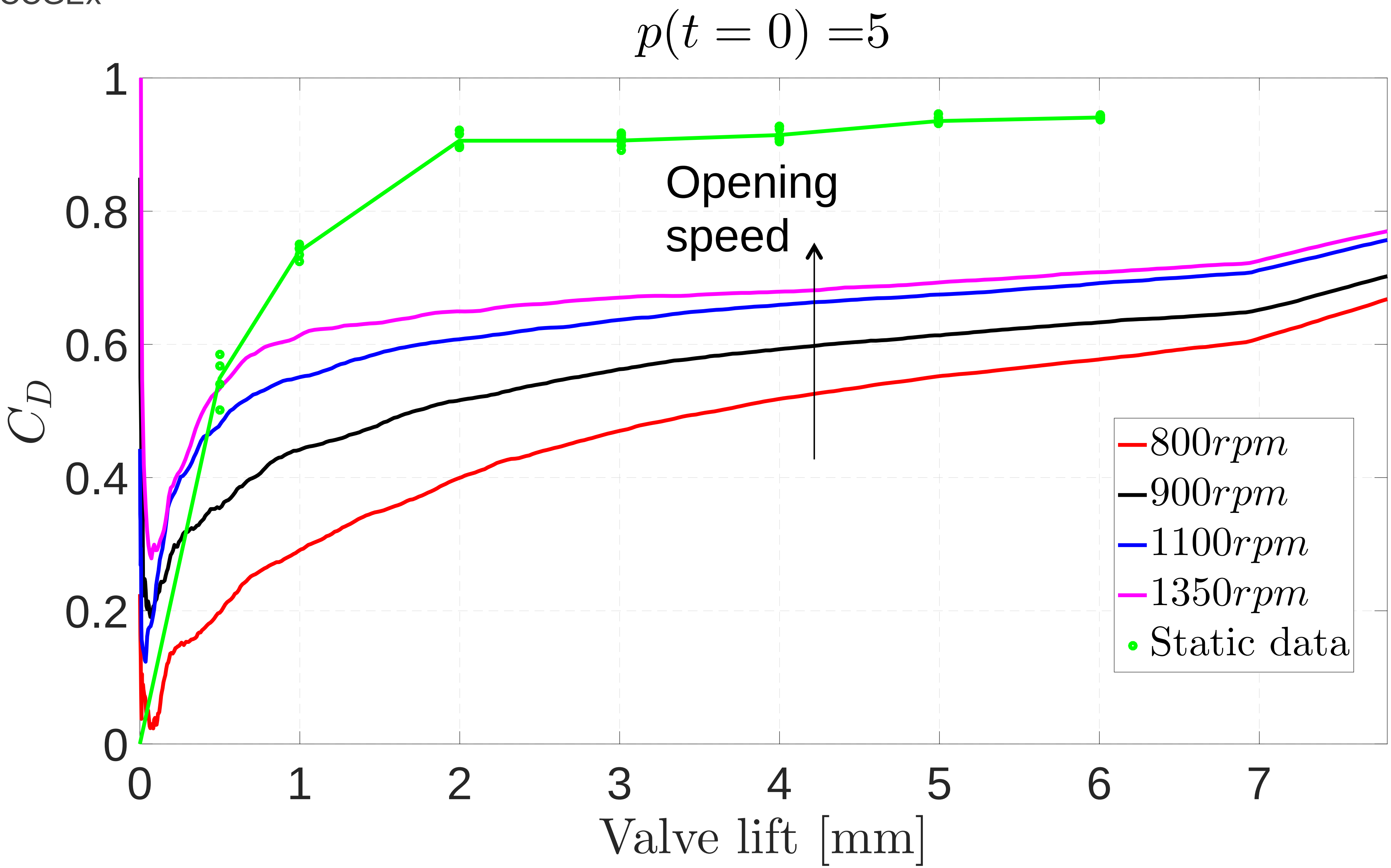

Radial position

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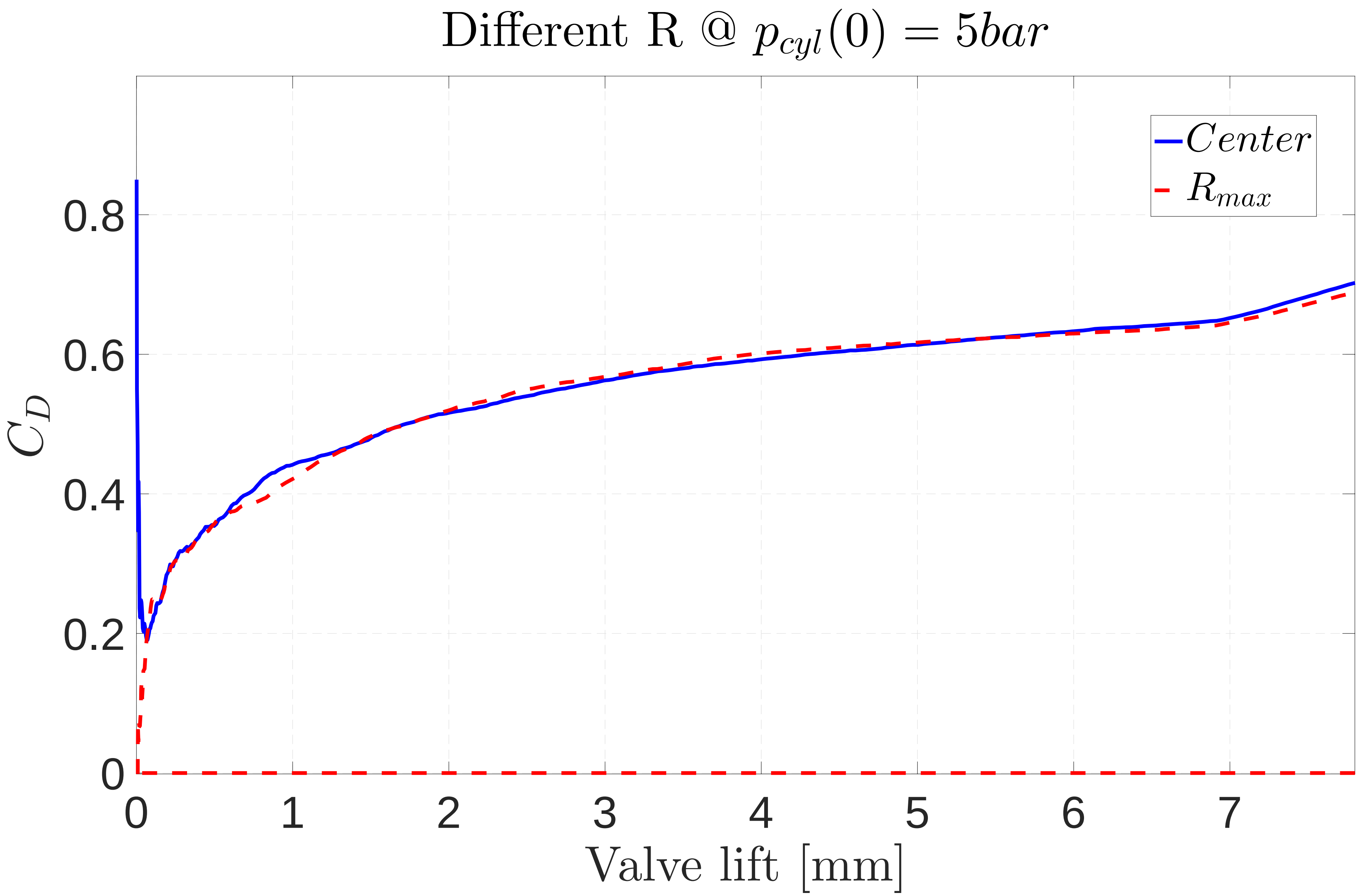

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Initial conclusions

- Assumption of pressure ratio independence:
  - Increasing the pressure ratio decreases the C_D-value
  - The static measurements of C_D seems relatively insensitive to pressure ratio
- The quasi-steady assumption:
  - Strong temporal effects
  - Faster opening leads to a higher C_D
  - Faster opening leads to a faster increase C_D
  - Static measurements over predicts the value of C_D
- C_D appears to be insensitive to radial position of the valve

Future work

- Test the effect of:
  - double valve combination (on going)
  - different valve opening profiles
  - different exhaust pipe geometries

Thank you for your attention!

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