Gas dynamics of exhaust valves

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Outline

• Background
• Experimental design
• Preliminary results
• Future work
Background – flow over exhaust valves

- Discharge coefficient

- Measurements of $C_D$ today:
  - Fixed valve lift
  - Low pressure ratios
  - Typical experiments performed in industry have a maximum $M \approx 0.3$ (incompressible)

- LES simulations by Y. Wang show
  - Large pressure ratio dependence on $C_D$

$$C_D = \frac{\dot{m}_{\text{real}}}{\dot{m}_{\text{ideal}}}$$
Objectives

Experimentally test the effects of:

• High pressure ratio (including choked flow conditions)
• Quasi-steady valve assumption
• Radial positioning of the valve
• Interaction of two valves
• Exhaust port geometry
Dynamic valve setup

\[ p_{\text{cyl},1}(t) \quad p_{\text{cyl},2}(t) \quad p_{\text{cyl},3}(t) \]

\[ p_{\text{throat}}(t) \]

\[ p_{\text{back},1}(t) \quad p_{\text{back},2}(t) \]

120 mm

177 mm
Time resolved mass flow

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

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.
\[ \dot{m} = \frac{dm}{dt} = \frac{V}{\gamma RT_0} \left( \frac{p_0}{p} \right)^{(\gamma - 1)/\gamma} \frac{dp}{dt} \]
Valve dynamics

The graph illustrates the valve lift over time at different engine speeds: 600 rpm, 900 rpm, and 1350 rpm. The x-axis represents time in seconds, ranging from 0 to 0.03 seconds, while the y-axis represents valve lift in millimeters, ranging from 0 to 14 mm. The curves show how valve lift increases with time for each engine speed.
Valve dynamics

Pressure ratio $p_{\text{throat}}/p_{0_{\text{cylinder}}}$

![Graph showing pressure ratio vs. valve lift for different speeds (600 rpm, 900 rpm, 1350 rpm) and critical point $p_{t}/p_{0}$]
Valve dynamics

Discharge coefficient (constant reference area)

- 600 rpm
- 900 rpm
- 1350 rpm

Valve lift [mm]

$C_D$

Valve dynamics

Discharge coefficient (constant reference area)

- 600 rpm
- 900 rpm
- 1350 rpm

Valve lift [mm]

$C_D$
Pressure ratio dependence

Discharge coefficient (constant reference area)

\[
p_0(t = 0)/p_{amb} = 4.81
\]

\[
p_0(t = 0)/p_{amb} = 4.00
\]

\[
p_0(t = 0)/p_{amb} = 3.66
\]

\[
p_0(t = 0)/p_{amb} = 3.54
\]

\[
p_0(t = 0)/p_{amb} = 3.41
\]

\[
p_0(t = 0)/p_{amb} = 2.93
\]
Pressure ratio dependence

\[ \Delta C_D = C_D - C_{D_{ref}} \]
Future work

• Dynamic valve experiments at
  - different pressure ratios @ different valve opening speeds
  - different radial position of the valve
  - different pressure ratios @ different radial position of the valve
  - different valve lift profiles
  - different exhaust pipe geometries
  - two-valve combination

• Static valve measurements using the CICERO flow facility

• Compare the mass-flow results with the vortex-shedding flow meter
Thank you!