Gas dynamics of exhaust valves

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Outline

- Previous experiments – steady state vs dynamic valve $C_D$ measurements
- Gas dynamics during valve opening
  - New flow visualization setup
  - Principle of Schlieren visualization
  - Flow physics in the exhaust port

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Previous experiments
$C_D$ for static and dynamic cases

$p_{0i} = 500$ kPa

Cylinder to back pressure ratio

Regime I

Regime II

\[ \ell/d = 0.143 \]
Surface flow visualisation

Shock wave
Recirculation bubble

Regime I
Regime II

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  - Flow physics in the exhaust port
Dynamic setup

- Pressure inlet
- Temperature measurement
- Pressure measurements
- Outlet
- Optical access
- Linear motor
- Cylinder volume
- Flow direction
- Exhaust port
- Valve
- Linear transducer

30 degree slice of the full geometry

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Static setup

Flow inlet
Schlieren setup

- Refractive index
- Density
- Gladstone-Dale constant
- Focal length

\[ n = 1 + K \rho \]

\[ \frac{dn}{dy} < 0 \]

Light source

Iris

f_1

Lenses

f_2

Schlieren knife

Camera

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Pressure ratio

\[
\frac{p_{\text{cyl}}}{p_{\text{back}}} \quad \ell/d = 0.143
\]

- \( \ell/d = 0.114 \)
- \( \ell/d = 0.143 \)
- \( \ell/d = 0.171 \)
- \( \ell/d \approx 0.155 \)
- Dynamic valve

- 800 rpm
- 900 rpm
- 1100 rpm
- 1350 rpm

\[ p_{\text{cyl}} \quad [\text{Pa}] \times 10^5 \]
Dynamic process (n = 1350 rpm)
Flow states in the dynamic process

Dynamic valve
\( \ell/d = 0.046928 \)

Dynamic valve
\( \ell/d = 0.18874 \)

Dynamic valve
\( \ell/d = 0.25558 \)

Subsonic  Supersonic
Comparing dynamic & static operations

**Dynamic**
\[\ell/d = 0.154\]
\[\mu = 42.8^\circ\]
\[M = 1.47\]

**Static**

**Regime I**
\[\ell/d = 0.155\]
\[\mu = 52.1^\circ\]
\[M = 1.27\]

**Regime II**
\[\ell/d = 0.155\]
\[\mu = 32.1^\circ\]
\[M = 1.88\]

\[M = \frac{1}{\sin \mu}\]
Comparing dynamic & static operations

**Dynamic**
\[ \ell/d = 0.154 \]
\[ \mu = 42.8^\circ \]
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**Static**

**Regime I**
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\[ M = \frac{1}{\sin \mu} \]
Conclusions

- The exhaust port flow has three distinct flow states:
  A. Overexpanded jet with free boundaries (small l/d)
  B. Overexpanded wall bounded jet with one free boundary (medium l/d)
  C. Fully expanded flow terminating in a normal pseudo-shock (large l/d)
- The dynamic discharge process goes through flow states A - C, showing mainly a dependency on l/d.
- The steady flow process show a transition from flow state B. (regime I) to flow state C. (regime II) (function of cylinder pressure) at lower l/d compared to the dynamic process.
- The characteristics of the state B jet (shock pattern, shape, Mach number) differs between dynamic and static operations.
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