Vehicle Specific Power: A Useful Parameter for Remote Sensing and Emission Studies

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Effect of Driving Conditions on Emissions

- Driving conditions may strongly influence emissions
  - e.g. commanded enrichment at high power demand

- Problems:
  - False high emitters / False clean cars in remote sensing
    - Texas Remote Sensing Study (CRC 98): 65% of cars at 5-6 mph/sec are high CO emitters
  - Difficult to compare between RS, dyno cycles, & models
  - Difficult to capture on emissions models
    - MOBILE, EMFAC: EF * Speed Correction * Cycle Correction
    - Modal, Neural Network: very detailed & complex
**Vehicle Specific Power (VSP)**

\[ VSP = \frac{\text{Power}}{\text{Mass}} = \frac{\frac{d}{dt}(E_{\text{Kinetic}} + E_{\text{Potential}}) + F_{\text{Rolling}} \cdot v + F_{\text{Aerodynamic}} \cdot v + F_{\text{internal friction}} \cdot v}{m} \]

\[ \approx v \cdot a \cdot (1 + \varepsilon_i) + g \cdot \text{grade} \cdot v + g \cdot C_R \cdot v + \frac{1}{2} \rho_a C_D \frac{A}{m} (v + v_w)^2 \cdot v + C_{if} \cdot v \]

**Previous Work:**

- **Specific Power** = 2 \cdot v \cdot a \quad \text{(EPA, 1993)}
- **Positive Kinetic Energy** = Σ pos(SP_i)/ Σ distance \quad \text{(Watson et al., 1983)}
- **DPWRSUM** = Σ |SP_i - SP_{i-1}| \quad \text{(Webster and Shih, 1996)}
Vehicle Specific Power (II)

For typical U.S. light-duty vehicles and light-duty trucks (better estimates of the resistance coefficients should be used when available):

\[
VSP = \frac{\text{Power}}{\text{Mass}} \approx 1.1 \cdot v \cdot a + 9.81 \cdot \text{grade} \cdot v + 0.213 \cdot v + 0.000305 \cdot (v + v_w)^2 \cdot v
\]

with VSP in kW/Metric Ton, v (speed) and v_w (headwind into the vehicle) in m/s, a (acceleration) in m/s^2, grade defined as vertical rise/horizontal distance.

\[
VSP = \frac{\text{Power}}{\text{Mass}} \approx 0.22 \cdot v \cdot a + 4.39 \cdot \text{grade} \cdot v + 0.0954 \cdot v + 0.0000272 \cdot (v + v_w)^2 \cdot v
\]

(VSP in kW/Metric Ton, v and v_w in mph, a in mph/sec)
VSP in Emissions Certification Cycles

Federal Test Procedure "Bag 1"

- Rolling Resistance
- Aerodynamic Resistance
- Kinetic Energy Change
- Speed

VSP Specified at each point
VSP in US06 Driving Cycle

![Graph showing VSP in US06 Driving Cycle]

- **Time (sec)**: 0, 25, 50, 75, 100, 125, 150, 175, 200, 225
- **Speed (mph)**: -60, -40, -20, 0, 20, 40, 60
- **Specific Power (kW/Metric Ton)**
- **Rolling Resistance**
- **Aerodynamic Resistance**
- **v*a**
- **Max. SP on FTP**

Graph shows the relationship between speed and power over time, highlighting specific power and resistance components.
VSP in European ECE2 Cycle
VSP Levels of Various Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>VSP (kW/ Metric Ton):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. Rated Powers</td>
<td>44 - 112</td>
</tr>
<tr>
<td>0 to 60 mph in 15 seconds</td>
<td>33</td>
</tr>
<tr>
<td>60 mph up a 4% grade</td>
<td>23</td>
</tr>
<tr>
<td>Maximum in FTP/IM240</td>
<td>23</td>
</tr>
<tr>
<td>Rem. Sensing site means</td>
<td>10 - 15</td>
</tr>
<tr>
<td>Average in IM240</td>
<td>8</td>
</tr>
<tr>
<td>ASM 5015</td>
<td>6</td>
</tr>
<tr>
<td>ASM 2525</td>
<td>5</td>
</tr>
</tbody>
</table>
Use of VSP Distributions

Characterize & Compare Driving Cycles, Remote Sensing Sites, or Models
VSP Distributions at RS Sites in Denver

Number of RSD Measurements vs. Specific Power

Vehicle     Specific Power kW/t
Advantages of VSP

- Captures dependence of emissions on power
  - Directly specified in certification cycles
- Can be calculated from roadside measurements
  - Mass only appears in aerodynamic term
- One-dimensional
- Direct physical interpretation
Emissions vs. VSP (1 Vehicle)

Sec-by-sec data for a 1994 Jeep Cherokee in HL07 dyno cycle, from SFTP CD-ROM (Haskew et al., 1994)
Binned Sec-by-sec data for a 1994 Jeep Cherokee, from SFTP CD-ROM (Haskew et al., 1994)
Emissions vs. VSP (1 Vehicle)

Binned Sec-by-sec data for a 1994 Jeep Cherokee, from SFTP CD-ROM (Haskew et al., 1994)
VSP > Max. VSP on FTP is good predictor of enrichment
Onset of Enrichment

Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)
CO Emissions vs. Several Parameters (6 Vehicles)

Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)
NO\textsubscript{x} Emissions vs. VSP and Power (6 Vehicles)

Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994)
Effect of Payload

Binned Sec-by-sec data from chassis dynamometer tests of SFTP CD-ROM (Haskew et al., 1994) for a 1993 Ford 250
Residence Time in Exhaust System

- Exhaust that leaves the tailpipe at the remote sensor was generated in the engine 1-25 meters before (when VSP>0)
  - Avoid decelerations at high speed
VSP: Implications for Emission Research

- Remote Sensing:
  - Improve clean screen and high emitter detection
    - Valid if $3 \text{ kW/t} < \text{VSP} < 22 \text{ kW/t}$
    - E.g. LA 96: 26% high CO emitters are suspect of enrichment
  - Relate RS results to I/M test results
  - Quantify real emissions at high power levels

- Compare results of:
  - RS sites
  - Dynamometer tests
  - Emission models

- Better representation of power in models
  - Use VSP distribution
Ultra Low Emissions Vehicle

Can screen out power enrichment in RS
Remote Sensing and Dyno Data vs. VSP

![Graph showing average CO emission (%) vs. vehicle specific power (kW / Metric Ton). The graph includes different data sets for Engine-out, Tailpipe, Los Angeles 96 Remote Sensing, and Denver 97-98 Remote Sensing.]

→ Allows Comparison and Interpretation
Remote Sensing and Dyno Data vs. VSP (II)

Los Angeles 96 Remote Sensing
Chicago 97 Remote Sensing
Engine-Out HC for 1 vehicle
Tailpipe HC for 1 vehicle
Correction for Power Demand

- Allows comparison of results of different methods and conditions
  - IM240 and remote sensing
  - Model different cities & road types
Conclusions

• Vehicle Specific Power (VSP)
  – Captures dependence of emissions on power
    • Specified in driving cycles
  – Roadside measurable
  – One dimensional, physically meaningful

• Applications
  – Improve low and high emitter detection on RSD
  – Common metric for emission studies
    • Compare RS, I/M tests, dyno cycles, models
  – Improve emission models