Road Vehicle Performance:
Introduction and Resistance

CE 322
Transportation Engineering
Dr. Ahmed Abdel-Rahim

Introduction to Road Vehicle Performance

Roadway design is governed by:
- Vehicle capabilities
  - acceleration/deceleration
  - braking
  - cornering (chap. 3)
- Human capabilities (late chap. 2, chap. 3)
  - perception/reaction times
  - eyesight (peripheral range, height above roadway)

Introduction to Road Vehicle Performance

Basis for roadway design guidelines:
- length of acceleration / deceleration lanes
- maximum grades
- stopping-sight distances
- passing-sight distances
- setting speed limits
- timing of signalized intersections
How does performance affect max grades?

Introduction

Studying vehicle performance serves two important purposes:
1. insight into
   1. roadway design
   2. traffic operations and
   3. compromises
2. basis to assess impact of advancing vehicle technologies on design guidelines
Tractive Effort and Resistance
- Opposing forces determining straight-line performance
- Tractive effort = force available to perform work
- Resistance = force impeding vehicle motion

Tractive Effort and Resistance
- Major sources of vehicle resistance:
  - Aerodynamic
  - Rolling (originates from the roadway surface/tire interface)
  - Grade or gravitational

Tractive Effort and Resistance
- Illustration of forces with vehicle force diagram

Aerodynamic Resistance
- Effect of speed?
- Sources:
  - Turbulent air flow around vehicle body ($\approx 85\%$)
  - Friction of air passing over vehicle body ($\approx 12\%$)
  - Air flow through vehicle components ($\approx 3\%$)
Aerodynamic Resistance

- Aerodynamic resistance force equation:

\[ R_a = \frac{\rho}{2} C_D A_f V^2 \]  

(Eq. 2.3)

- Air density properties (Table 2.1):
  - \( \uparrow \) altitude, \( \downarrow \) density
  - \( \uparrow \) temperature, \( \downarrow \) density

- Drag coefficient accounts for all 3 sources
- Road vehicle drag coefficients \( \rightarrow \) Table 2.2 (for different types)
- Drag coefficients trend \( \rightarrow \) Table 2.3 (past 35 years)
  - What is the trend?
  - What impact could this have on roadway design?

- How sensitive is \( R_a \) to speed?
- Let’s develop a relationship for how much power is needed to overcome \( R_a \).
Aerodynamic Resistance

- Power is the product of force and speed, so multiplying Eq. 2.3 by speed gives:
  \[ P_x = \frac{\rho}{2} C_{rA} A V^3 \]
  \[ \text{(Eq. 2.4)} \]

- or, since 1 horsepower = 550 ft-lb/sec,
  \[ hp_x = \frac{\rho C_{rA} A V^3}{1100} \]
  \[ \text{Sensitivity of power to speed...} \]

Rolling Resistance \((R_{rl})\)

- Source
  - vehicle's internal mechanical friction
  - Pneumatic tires and interaction with the roadway.
  - Tire deformation (≈90%)
  - Tire slippage and air circulation around tire & wheel (about 6%)
  - Tire penetration/surface compression (about 4%)

- Factors affecting \(R_{rl}\)
  - Rigidity of tire and roadway surface
  - Tire inflation pressure and temperature
  - Vehicle speed

- Approximated as product of a friction term (coefficient of rolling resistance) and vehicle weight.

- Coefficient of rolling resistance \((f_{rl})\) on paved surfaces
  \[ f_{rl} = 0.01 \left(1 + \frac{V}{147}\right) \quad \text{with } V \text{ in ft/s} \]
  \[ \text{(Eq. 2.5)} \]

  \[ f_{rl} = 0.01 \left(1 + \frac{V}{44.73}\right) \quad \text{with } V \text{ in m/s} \]
**Rolling Resistance ($R_{rl}$)**

- Rolling resistance approximation:
  \[ R_{rl} = f_{rl}W \cos \theta \]
- For a 10% grade, what is the cosine term?
  \[ R_{rl} = f_{rl}W \]

(Eq. 2.6)

**Grade Resistance ($R_g$)**

- What is the grade resistance to vehicle motion?

\[ R_g = W \sin \theta_g \]
\[ \sin \theta_g \approx \tan \theta_g \]
\[ R_g \approx WG \]

(Eq. 2.9)