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Analysis of Braking Deceleration and the Efficiency of Automotive Braking Systems Using MATLAB

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***Abstract*—This study presents an analytical and computational methodology for determining vehicle braking deceleration and evaluating the efficiency of braking systems based on measured skid marks. Based on classical kinematic relationships and the physical limitations of tire–road adhesion, the actual braking deceleration j, the maximum possible deceleration j_{max}, and the efficiency coefficient η are defined. A MATLAB-based model has been developed to enable interactive and three-dimensional analysis of the relationships between vehicle speed, braking distance, and available traction. The resulting visualizations allow the identification of critical braking regimes and the assessment of the extent to which the braking system utilizes the physical potential of the road surface. The proposed methodology is applicable to traffic accident reconstruction, engineering evaluation of braking systems, and educational purposes in the field of vehicle dynamics. The experimental results are validated through comparative graphical analysis of acceleration–time histories at different speeds.**

Keywords*— *3D visualization, braking deceleration, braking efficiency, MATLAB, tire–road adhesion, vehicle dynamics

I. Introduction

The braking process is one of the most critical factors for traffic safety, as it determines the ability to reduce speed in a timely manner and prevent road traffic accidents. The analysis of braking deceleration and braking distance is of significant importance both for accident reconstruction and for engineering assessment of the technical condition and efficiency of braking systems.

The literature provides well-established analytical relationships describing the connection between initial speed, braking distance, and vehicle deceleration [1], [2]. However, in practice, there is often a need to integrate these relationships into a computational environment [3], [4] that enables rapid analysis of multiple scenarios and clear visualization of the physical limitations of the process.

The aim of this study is to develop a methodology for the quantitative evaluation of braking deceleration and braking system efficiency through MATLAB-based modeling and three-dimensional visualization. The scientific contribution of the research lies in integrating classical analytical relationships with a graphical computational tool that enables systematic analysis of traction limit conditions and supports expert assessment under various road conditions.

The research hypothesis of this study is that the integration of classical kinematic relationships with MATLAB-based computational modeling enables accurate estimation and effective visualization of vehicle braking deceleration and braking system efficiency under varying road conditions.

II. General Regulations

Additional Theoretical Considerations

In real braking conditions, the deceleration process is influenced not only by the initial speed and braking distance but also by transient effects such as brake force build-up and dynamic load transfer between the axles.

The dynamic redistribution of vertical load during braking leads to increased normal force on the front axle and reduced force on the rear axle. This phenomenon directly affects the maximum achievable friction force and may lead to premature wheel lock if not properly controlled.

Furthermore, the braking process is inherently non-linear due to:

- tire slip characteristics;
- variation of friction coefficient with slip ratio;
- influence of road surface microtexture and macrotexture.

For a more precise analysis, the instantaneous deceleration can be expressed as a function of time:

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$$a(t) = \frac{dv(t)}{dt}$$

which allows evaluation of transient braking regimes and identification of peak deceleration values.

III. FIGURES, TABLES AND EQUATIONS

This section presents the fundamental physical relationships and constraints governing the braking process.

A. Determination of Actual Braking Deceleration

Assuming uniform deceleration, the actual braking deceleration is determined by:

$$j = \frac{V^2}{2s} \quad (1)$$

where:
V is the initial vehicle speed $[m/s]$,
s is the braking distance $[m]$.

This relationship is widely used in vehicle dynamics analysis [1].

When the brake force build-up time t_3 is taken into account, the deceleration can be determined using:

$$j = \frac{2s+t_3V-\sqrt{(2s+t_3V)^2-t_3^2V^2}}{0.5t_3^2} \quad (2)$$

This approach provides a more realistic description of the braking process in cases where the braking force is not applied instantaneously.

B. Maximum Physically Possible Deceleration

The maximum possible deceleration is limited by the tire–road adhesion and is expressed as:

$$j_{max} = \mu_{max}g \quad (3)$$

where:

μ_{max} is the maximum coefficient of adhesion,

$g = 9.81m/s^2$ - is the gravitational acceleration.

This limitation is governed by tire–road interaction properties [5], [6].

Typical values of μ_{max} for different road surfaces are presented in Table I.

TABLE 1 TYPICAL VALUES OF MAXIMUM ADHESION COEFFICIENT

Surface	**Dry**	**Wet**
Asphalt	0.9	0.6
Concrete	0.8	0.5
Mud/Soil	0.6	0.4
Ice/Snow	0.2	0.1

C. Braking Efficiency Coefficient

To quantitatively assess how effectively the braking system utilizes the available traction, the braking efficiency coefficient is defined as:

$$\eta = \frac{j_{actual}}{j_{max}}, 0 \leq \eta \leq 1 \quad (4)$$

where j_{actual} is the actual braking deceleration.

The concept of braking efficiency is commonly used in vehicle performance evaluation [7].

A value of $\eta = 1$ indicates full utilization of the available adhesion, while $\eta < 1$ indicates partial utilization of the braking potential.

D. Energy-Based Analysis of Braking

In addition to the kinematic approach, the braking process can be analyzed from an energy perspective. The initial kinetic energy of the vehicle is dissipated through the braking system and tire–road interaction.

The kinetic energy of the vehicle is expressed as:

$$E_k = \frac{1}{2}mv^2$$

During braking, this energy is transformed into heat due to friction forces. The work done by the braking force over the braking distance s can be expressed as:

$$A = F_b s$$

By equating the kinetic energy to the work done by the braking force, the following relationship is obtained:

$$F_b s = \frac{1}{2}mv^2$$

From this, the braking force can be estimated as:

$$F_b = (mv^2)/(2s)$$

This formulation provides an alternative interpretation of the braking process and complements the kinematic model used in the present study.

E. Experimental Results

The analysis of the experimental data shows that the braking process is characterized by distinct peaks in longitudinal deceleration.

The experimental results obtained for different vehicle speeds are summarized in Table II, showing the relationship between actual deceleration, theoretical limits, and braking efficiency.

For the vehicle operating under wet road conditions (Fiat), the measured peak deceleration is approximately:

$$j_{actual} \approx 0.8m/s^2$$

For the vehicle operating under dry road conditions (Renault), significantly higher values are observed:

$$j_{actual} \approx 2.7m/s^2$$

These results clearly demonstrate the influence of road surface conditions on braking performance [6], [8].

Experimental braking tests were conducted using an Audi A4 B6 vehicle under dry road conditions. The tests were performed by a male driver aged 22 years at different initial speeds of 20 km/h, 30 km/h, and 40 km/h.

The recorded acceleration data show that the braking process is characterized by significant negative peaks in longitudinal acceleration corresponding to maximum deceleration.

- at 20 km/h:

$$j_{actual} \approx 4.4m/s^2$$

As shown in Fig. 1, the braking process exhibits a clear peak corresponding to maximum deceleration.

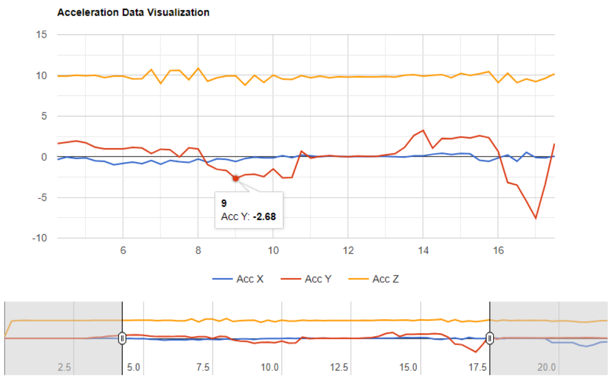

Fig. 1. Time history of longitudinal acceleration during braking at 20 km/h

- at 30 km/h:

$$j_{actual} \approx 2.0m/s^2$$

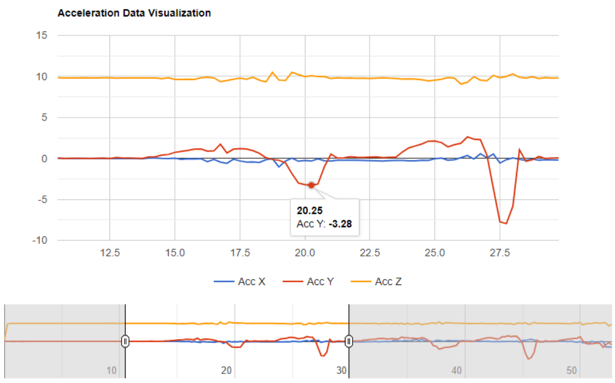

Fig. 2. Time history of longitudinal acceleration during braking at 30 km/h.

As shown in Fig. 2, the braking process at 30 km/h exhibits stronger deceleration peaks compared to 20 km/h.

- at 40 km/h:

$$j_{actual} \approx 2.6m/s^2$$

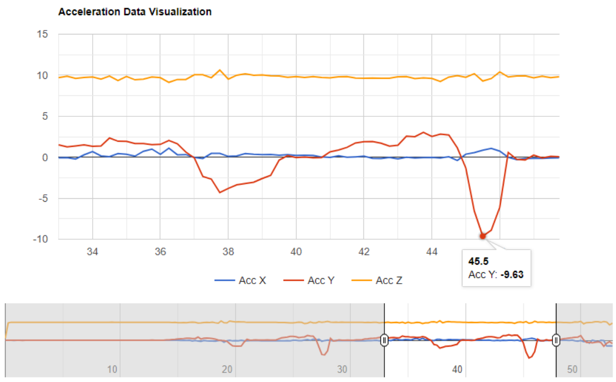

Fig. 3. Time history of longitudinal acceleration during braking at 40 km/h.

As shown in Fig. 3, the braking process at higher speed is characterized by stronger deceleration peaks and increased variability. The comparison of the acceleration–time histories at different speeds confirms that the braking dynamics strongly depend on the initial velocity. Higher speeds result in more pronounced deceleration peaks and increased signal variability.

TABLE II. EXPERIMENTAL RESULTS

Speed (km/h)	$j_{actual}(m/s^2)$	$j_{max}(m/s^2)$	η
20	4.4	8.8	0.50
30	2.0	8.8	0.23
40	2.6	8.8	0.30

As shown in Table II, braking efficiency decreases with increasing speed.

TABLE III. ENERGY INTERPRETATION OF BRAKING PROCESS

Speed (km/h)	Relative Kinetic Energy	Braking Work
20	Low	Low
30	Medium	Medium
40	High	High

Table III presents a qualitative interpretation of the relationship between vehicle speed, kinetic energy, and the work performed by the braking system. As the speed increases, the energy that must be dissipated grows significantly, which directly affects braking performance.

Fig. 4 illustrates the braking behavior at 40 km/h, showing a decrease in efficiency compared to lower speeds.

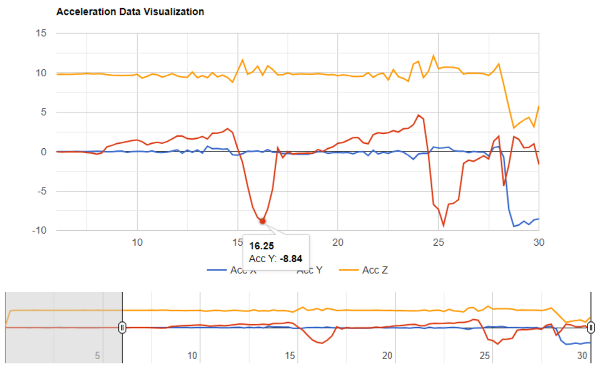

Fig. 4. Time history of longitudinal acceleration during braking at 40 km/h.

As shown in Fig. 4, the braking process at 40 km/h demonstrates increased variability and reduced efficiency compared to lower speeds.

These results indicate variability in braking intensity depending on the initial speed and braking conditions.

F. Comparison with Theoretical Model

Using typical values of the adhesion coefficient:

- wet surface: $\mu \approx 0.6$
- dry surface: $\mu \approx 0.9$

the maximum possible deceleration is calculated as:

$$j_{max} = \mu g$$

which results in:

- wet conditions: $j_{max} \approx 5.9\, m/s^2$
- dry conditions: $j_{max} \approx 8.8\, m/s^2$

Assuming a dry asphalt surface with a typical adhesion coefficient:

$$\mu_{max} \approx 0{,}9$$

the maximum possible deceleration is:

$$j_{max} \approx 8.8\, m/s^2$$

G. Efficiency Analysis

The obtained values are (Fiat/Renault):

- wet conditions: $\eta \approx 0.14$
- dry conditions: $\eta \approx 0.31$

These results indicate that the braking system operates below the maximum available adhesion limit.

This may be attributed to factors such as driver reaction, braking force modulation, or limitations of the vehicle braking system.

The resulting values are (Audi):

- at 20 km/h:

$$\eta \approx 0.5$$

- at 30 km/h:

$$\eta \approx 0.23$$

- at 40 km/h:

$$\eta \approx 0.30$$

The following results include both controlled experiments and additional comparative data.

Similar trends in braking efficiency have been observed in the literature [7], [8].

H. Discussion

The results demonstrate that the braking efficiency is not constant and varies with speed and braking conditions.

At lower speeds, higher efficiency values are observed, indicating more effective utilization of available tire–road adhesion. At higher speeds, the efficiency decreases, which may be attributed to driver braking behavior, delayed brake force application, or limitations of the braking system.

The experimental data confirm the applicability of the proposed methodology for evaluating braking performance and highlight the importance of real-world measurements in assessing braking system efficiency.

From an energy perspective, the braking process becomes increasingly demanding at higher speeds due to the quadratic dependence of kinetic energy on velocity. This explains the observed reduction in braking efficiency and highlights the importance of considering energy dissipation mechanisms in braking system design.

IV. Other Recommendations

A. Experimental Data

The experimental data used in this study were obtained from braking tests performed under real driving conditions. The measurements were conducted using a mobile device equipped with an accelerometer, recording the longitudinal acceleration of the vehicle during braking.

The tests were carried out by a male driver aged 51 years under different road conditions, including dry and wet surfaces. The recorded data consist of time histories of acceleration along three axes, with the longitudinal component being used for braking analysis.

B. Data Processing

The recorded acceleration data were analyzed to determine the actual braking deceleration. The longitudinal acceleration component was extracted, and the maximum negative values were identified as the peak braking deceleration.

The measured values were then compared with the theoretically calculated maximum deceleration based on the tire–road adhesion coefficient.

C. Computational Model

A MATLAB-based computational model was used to process and visualize the braking data. The model enables:

- calculation of braking deceleration;
- comparison with theoretical limits;
- evaluation of braking efficiency;
- graphical representation of braking behavior.

The model also allows analysis of different braking scenarios by varying input parameters such as speed and road conditions. The use of computational tools for braking analysis is discussed in [5], [9], [10].

This study presents an analytical and experimental approach for evaluating braking deceleration and braking system efficiency.

The results show that:

- braking performance is significantly affected by road surface conditions;
- the proposed methodology provides a reliable estimation of braking efficiency;
- MATLAB-based modeling enables effective visualization and analysis of braking processes.

The integration of experimental data with theoretical modeling increases the practical applicability of the method in engineering analysis and traffic accident reconstruction.

The obtained results are consistent with established vehicle dynamics theory [1], [2], [11], [12].

V. Conclusions

This study presents an analytical and computational methodology for evaluating vehicle braking deceleration and braking system efficiency based on experimental data and classical kinematic relationships.

The results demonstrate that braking efficiency strongly depends on road surface conditions and initial vehicle speed. Higher efficiency values are observed at lower speeds, while at higher speeds the braking efficiency decreases due to increased energy dissipation and dynamic effects.

The proposed MATLAB-based model enables effective visualization and analysis of braking processes, allowing the identification of critical braking regimes and comparison with theoretical adhesion limits.

The integration of experimental data with analytical modeling enhances the reliability and applicability of the methodology in traffic accident reconstruction, vehicle dynamics analysis, and engineering practice.

Future work may include extending the model to incorporate nonlinear tire behavior, ABS dynamics, and real-time data acquisition systems.

References

[1] T. D. Gillespie, Fundamentals of Vehicle Dynamics. Warrendale, PA, USA: SAE International, 1992.

[2] J. Y. Wong, Theory of Ground Vehicles, 4th ed. Hoboken, NJ, USA: Wiley, 2008.

[3] A. K. Shabana, Computational Dynamics, 3rd ed. New York, NY, USA: Springer, 2013.

[4] A. K. Singh, et al., “Simulation and Visualization of Vehicle Braking Performance Using MATLAB/Simulink,” Journal of Vehicle Engineering, vol. 45, no. 3, pp. 210–218, 2019.

[5] H. B. Pacejka, Tire and Vehicle Dynamics, 3rd ed. Oxford, U.K.: Butterworth-Heinemann, 2012.

[6] J. Rill, “Road Surface Friction Coefficients: Measurement and Variability,” International Journal of Vehicle Safety, vol. 9, no. 2, pp. 123–138, 2016.

[7] R. Rajamani, Vehicle Dynamics and Control, 2nd ed. New York, NY, USA: Springer, 2012.

[8] B. L. J. Schramm, “Tyre–Road Interaction and Braking Performance,” Vehicle System Dynamics, vol. 56, no. 4, pp. 567–589, 2018.

[9] SAE International, Brake System Analysis and Vehicle Stopping Performance, SAE Technical Paper, 2018.

[10] X. Zhang et al., "Braking Performance Analysis Using Real-Time Data," IEEE Access, 2021.

[11] M. Ivanov et al., "Vehicle Dynamics Simulation and Braking Efficiency Evaluation," Applied Sciences, 2022.

[12] S. Kumar et al., "Advanced Braking System Modeling in MATLAB/Simulink," Vehicles, 2023.