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# Analysis of the Relationship Between the Motion Resistive Force and the Road Surface for Special Purpose Off-Road Vehicle

**Marek Nowakowski [1*], Przemyslaw Siminski [1], Krzysztof Kosiuczenko [1]**

[1] Military Institute of Armoured and Automotive Technology, Okuniewska 1, 05-070 Sulejówek, Poland

**Abstract:** A comprehensive understanding of the relationship between motion resistive force and road surface is essential for operation of special purpose off-road vehicles. This research focuses on the testing of a developed Light Terrain Vehicle (LST). Design of LST special vehicle as well as used equipment for testing purposed is descried. The paper presents carried out testes on typical road surfaces closely related to the operational conditions. The study enables defining operational usage of developed special purpose off-road vehicle in diverse environments.

**Keywords:** Light Terrain Vehicle, motion resistive force, testing special purpose vehicles

## 1. Introduction

Introducing new vehicle brands or types into production demands thorough preliminary research. These tests encompass various dimensions, parameters, and features crucial for assessing the vehicle's quality and construction accuracy.

Measurement of motion resistive forces is crucial for special vehicles due to their unique operational requirements [1-2]. Engineers use these measurements to tailor vehicle design and performance for specific missions, whether it's maximizing fuel efficiency for long-range deployments or minimizing energy consumption during emergency response [3]. Understanding resistive forces is also important for ensuring adaptability to different terrains, such as off-road environments or extreme weather conditions [4]. Considering these forces, engineers can design systems that navigate diverse landscapes effectively, ensuring optimal performance.

Additionally, measuring resistive forces helps evaluate payload capacity and equipment integration. Special vehicles often carry heavy payloads or specialized gear like military supplies or medical equipment, and understanding resistive forces helps determine power requirements and overall performance. In military applications, reducing aerodynamic drag and rolling resistance is crucial for survivability and operational stealth.

When a car moves in a straight line, it experiences forces that oppose its motion, known as resistance. Additionally, there is a counteracting longitudinal ground reaction induced by the driving torque transmitted from the engine to the car's drive wheels.

All forces acting on a car in straight-line motion can be presented in the form of a formula called the car's resistance balance, which in the most general case of straight-line

$$F_n = F_t + F_p + F_w + F_b + F_u \tag{1}$$

*** Corresponding author:** Marek Nowakowski, ***E-mail address:*** *marek.nowakowski@witpis.eu*

motion can be expressed as follows [5]:

This formula indicates that the motion force of the vehicle at any moment is equal to the sum of all the resistances occurring during the movement of the car. The movement resistance includes the following forces:

- *Fn – driving force,*
- *Ft – rolling resistance force,*
- *Fp – air resistance,*
- *Fw – slope force resistance,*
- *Fb – inertia resistance,*
- *Fu – pulling resistance.*

Rolling resistance is consistently influenced by various factors, contributing significantly to the primary resistance experienced by a car. These factors include the tire's construction and materials, such as rubber compound, which determine how the tire deforms during rolling [6]. The inflation pressure of the tire also plays a significant role, with underinflated tires increasing rolling resistance and potentially leading to issues like wheel rim deformation under abnormal conditions [7]. Additionally, the impact of rolling resistance is influenced by the texture and composition of the road surface.

On the other hand, slope resistance and inertia resistance occur intermittently. Slope resistance is only present when ascending, representing the parallel component of gravity's force. During descent, this component reverses, aiding the vehicle's motion. Inertia resistance arises solely during acceleration, as the vehicle's inertia opposes its direction of movement.

The determination of the coefficient of rolling resistance for vehicle wheels involves various methods [8-10]. While bench tests are an option, practical methods are often preferred due to their closer alignment with real-world conditions. Lab tests may offer limited surface options and may fail to fully replicate actual scenarios, potentially leading to result discrepancies. Oppositely, practical approaches, such as road tests using test vehicles, provide a more authentic evaluation. These methods, including coasting, downhill rolling, towing, drive torque measurement, maximum speed assessment, and fuel consumption monitoring, follow closely real-world conditions.

Conducting road tests using special-purpose vehicles allows for a more precise assessment of performance. These tests enable the direct observation of interactions with diverse surfaces, and obstacles encountered in their designated operational environments.

## 2. Description of developed special purpose vehicle

The Light Terrain Vehicle (LST) was developed by a consortium comprising the Military Institute of Armour and Automotive Technology (WITPIS), Military University of Technology (WAT), and the company Szczesniak Pojazdy Specjalne to operate effectively in all terrain conditions (see Fig 1) [11]. Based on the Land Rover Defender 110 suspension, the LST offers exceptional drivability characteristics, high capacity, and modularity in rough terrain. Constructed using appropriate materials to achieve strength and lightness, the vehicle features an aluminium sheathing and load structure attached to the main frame with vibration-absorbing rubber components. Equipped with a powerful engine capable of operating in various conditions, along with a durable suspension system, the LST is well-suited for a wide range of applications. Its design also allows for easy reconfiguration and adaptation for different payloads and equipment.

Figure 1: View of Light Terrain Vehicle [11]

## 3. Installed system for testing purpose

The measurement set consists with very precise navigation module GNSS INS with computational unit for data processing. For testing purpose was used a new generation of integrated GPS, GLONASS, GALILEO, QZSS, BEIDOU and L-band navigation system and a high-performance module that determines position, speed and orientation. Inertial Labs uses an advanced dual-antenna GNSS receiver, barometer, 3-axis full-temperature calibrated precision Fluxgate magnetometers, accelerometers and gyroscopes to provide accurate position, speed, heading, pitch and roll of a moving vehicle [13]. Antennas were installed on the loading part of the vehicle to ensure continuous satellite tracking during driving conditions (Fig.2). The testing set utilized included inertial units, enabling the recording of the test vehicle's velocity and its location on the map.

Figure 2: View of installed antennas of GNSS system

The inertial unit contains an extended filter for data coming from on-board sensors as shown in Fig 3.

The data captured by these sensors are processed using software packages and libraries for data acquisition, processing, and analysis. The configured set was used to record the required parameters for further analysis of relation between motion resistive force and the road surface.

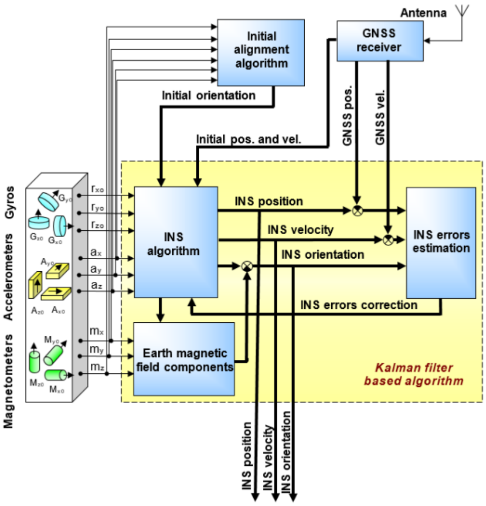


Figure 3: Block diagram of Inertial Labs system [13].

## 5. Experimental data acquisition

To ensure the high quality and reliability of the collected data, repeatable measurements were conducted. By carrying out measurements in a controlled and consistent manner, any variability or discrepancies in the results can be minimized, thus enhancing the accuracy of the analysis. Consistency in the testing environment is maintained to eliminate errors and obtain reliable data, with efforts made to conduct measurements in similar weather conditions to reduce potential sources of variability.

Additionally, the sensors and measurement equipment undergo calibration before each testing session to ensure accurate data collection. Calibration procedures involve setting precision of the sensors minimizing measurement errors and ensuring the reliability of the collected data.

(*a*)

(*b*)

Figure 4: Measuring conditions: asphalt (a), gravel(b)

The selection of representative road surfaces as well as the implementation of procedures for repeatable measurements eliminate error in real field measurements. This approach ensures that the data collected accurately reflects real-world conditions, enhancing the validity and reliability of the analysis conducted on the relationship between motion resistive force and the road surface.

## 6. Results discussion

There are few methods to determine resistive force in the motion of a vehicle. This coefficient serves as a measure of road accessibility and is influenced by various factors, including road surface type, vehicle tires, and environmental conditions such as snow, rain etc.

Carried out research focuses on comparing the effects of various road surface types on the motion resistance of a developed LST vehicle. All tests were conducted on a flat section of the analysed surface, keeping the same weather conditions (including wind, temperature, and humidity) are maintained throughout. To ensure proper and reliable comparisons during testing, all other conditions apart from road type were the same. The implemented methodology was based on the vehicle acceleration to a defined speed and then declutching, allowing the movement resistance to a stop vehicle, while measuring the time for this process. Below are shown calculated results for asphalt (Fig 5) and gravel (Fig 6).

The achieved results have about 20% difference in the time to stop the vehicle, depending on the type of road surface. It should be underlined that such simplified approach allows effectively identify how different road surfaces affect the motion resistance of the LST vehicle, providing valuable insights for its future operational usage.

## 7. Conclusions

The importance of road surface type in determining the usage and adaptability of vehicles is discussed. It is emphasized that the characteristics of the surface on which vehicles operate significantly influence their flexibility and versatility.

Optimizing transportation systems and ensuring reliable vehicle operation hinges on understanding the impact of road surface types on vehicle performance and durability. simulation methods offer valuable insights, they have limitations. These models rely on assumptions that may introduce bias and lead to inaccurate predictions. Due to these limitations, it is advisable to complement simulation models with other methods to ensure accurate assessments of road surface impacts on vehicle performance.

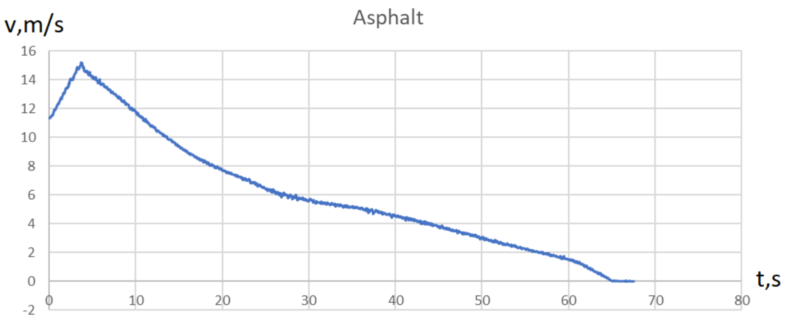


Figure 5: Characteristic of LST vehicle motion resistance for asphalt surface

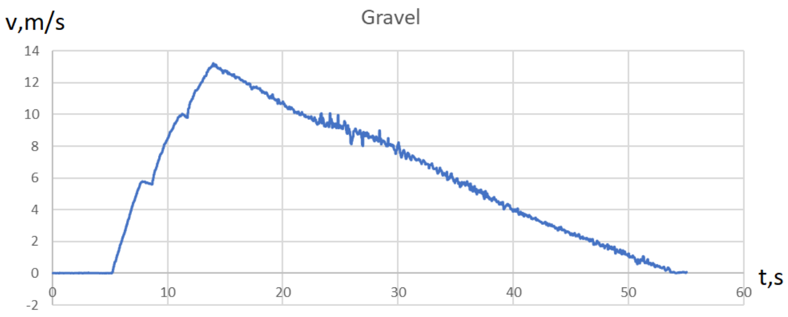


Figure 6: Characteristic of LST vehicle motion resistance for gravel surface

There are different laboratory devices to measure motion resistance in practice, but the empirical relationships obtained from field measurements depend on testing methods and conditions. Proposed simplified approach, which focused on determining motion resistance for typical road surfaces, has revealed valuable insights into the performance and durability of vehicles in real-world scenarios.

Special-purpose vehicles designed for off-road use must ensure flexibility to operate in urban areas characterized by asphalt roads as well as unstructured environment with gravel surfaces. The performance and durability of these vehicles are closely related to the road surface ensuring that vehicles are capable of operating efficiently across diverse road conditions.

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