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# Applications of pulleys and inclined plane in transport engineering

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***Abstract.*** This scientific paper presents original research and the authors personal views on the technical-economic and practical acceptance of pulley and inclined plane applications in transport engineering. Engineering specialists appreciate that the active type experiment carried out by practical determinations leads to concrete, important results in the field addressed. In order to demonstrate theoretically and practically what the specialists say, we have made a small-scale laboratory model in which we have experimented with situations similar to those encountered in real life. In this way, we have presented the front end of pulley systems used for lifting or towing damaged or damaged vehicles (motor vehicles) on trailer trailers, which are common in transport engineering. In this way, those interested can learn how these applications can be used in the laboratory but also in real life, the advantages and concrete results obtained when applied. Other experiments and applications of the laboratory mock-up are specified in the paper, in which the results, their usefulness, real-life applicability, how certain measuring instruments are used, the units of measurement and their conversions, as well as how to calculate the voltages occurring in lifting/pulling cables with pulleys are presented. The scale model can be successfully used in the laboratories of art and craft schools, high schools or colleges. In this way pupils or students can acquire practical knowledge in car knowledge or road vehicle dynamics laboratories. At the end of the work, conclusions in the field covered and further research directions are presented.

**Keywords:** *pulleys, hoists, inclined plane, transmission ratio, applications, automobiles.*

## Introduction

Throughout the ages, according to his needs, man has had to move himself and his burdens first by his own power; gradually, in order to make his work easier, he has developed devices, systems and means of transport and lifted [1], [2]. Among these we can mention the wheel, the raft or canoe, the pulleys, the hoists [3], [4] or the inclined plane - just a few inventions of overwhelming value, which formed the foundation for the exceptional development of techniques and means by which man conquered space and time. In order to ensure the need to climb to height or to descend to depth of materials, goods or heavy objects necessary for living or construction, man had to develop the necessary lifting facilities, then to adapt them to the specific means of traction; he then had to develop the knowledge and train himself to use or handle them. In order to avoid accidents, whether minor or serious, they had to develop rules or regulations for use. Thus, from the need to mobilise, to handle the necessities of daily life, the means emerged with which he moves, lifts or lowers his bulky objects or goods, according to certain rules, on land, underground, on water or in the air. Since nothing moves on this planet without transport, moving, handling or lifting, the facilities and means specific to these activities are of particular importance in meeting human needs. When the rules for maintenance or repair of motor vehicles are not observed and their propulsion systems fail, or when road accidents occur as a result of non-compliance with road traffic legislation, resulting in substantial material damage, whereby the vehicle or road vehicle loses its dynamic capabilities and can no longer propel itself, specific towing equipment is required. To this end, for road vehicles and motor vehicles, in particular those on wheels or tracks, which have been overturned, damaged in a road accident or whose drive, steering or transmission systems have broken down, towing, pulling them out of ditches or valleys. These means of transport are then loaded onto transporters (trailers) equipped with specialised equipment, which have a high tractive force, with the help of which they are loaded and moved to workshops or repair bases. As a rule, devices and installations consisting of pulleys and hoists are used for towing on these conveyors, which facilitate both the effort and work of the operators and the mechanical work developed by the engines of the exhaust machinery used to tow the defective equipment. The main objective of the paper is to highlight the applications of pulleys and inclined plane in the field of transport engineering, and the specific objectives are: to highlight the mechanical advantages of using pulleys for lifting or towing loads in transport; to determine the transmission ratio ***(i)*** of pulleys and to present the results of research in this field on experimental laboratory material.

## 1. Literature review

Archimedes was a great mathematician and engineer who was born in 287 b.C. (before Christ), in Syracuse, Sicily. He is known for many modern principles of mathematics and mechanics, and had a great understanding of the concept of mechanical advantage and how it can be used to move or lift heavy objects with little effort [5, p. 71]. The earliest evidence of scribes dates from ancient Egypt in the 12th Dynasty (1991-1802 b.C.) and Mesopotamia in the early 2nd millennium b.C. Simple machines are mechanical systems used to make work easier and consist of various simple mechanisms: levers, pulleys, gears, screws, inclined planes or wedges. In Roman Egypt, Hero of Alexandria (c. 10-70 a.C. after Christ) identified pulleys as one of six simple machines used to lift weights [6, p. 98]. The mechanical advantage of a machine or device is the ratio of input to output force. A good mechanical advantage is one that has a superunit value. For a device like a pulley, these forces are easy to determine [7, p. 71], [8, p. 4] .

Two or more forces may act on a simple device. In the general case, a ***force denoted F***, called the driving force, acts on the device and is used to move another force denoted ***R*** or ***Q***, called the ***resisting force***. Simple devices are used in practice either to amplify the forces or to make more advantageous use of them by changing the orientation of the active force. There are also situations where the resisting force must be much smaller than the active force in order not to destroy the mechanical system. A pulley is a simple mechanical device of the first-order lever category, consisting of a wheel with a groove at its periphery through which a cable, rope or chain passes. The ***pulley*** shaft is fixed in a fork ending in a hook. It allows an economy of force to be

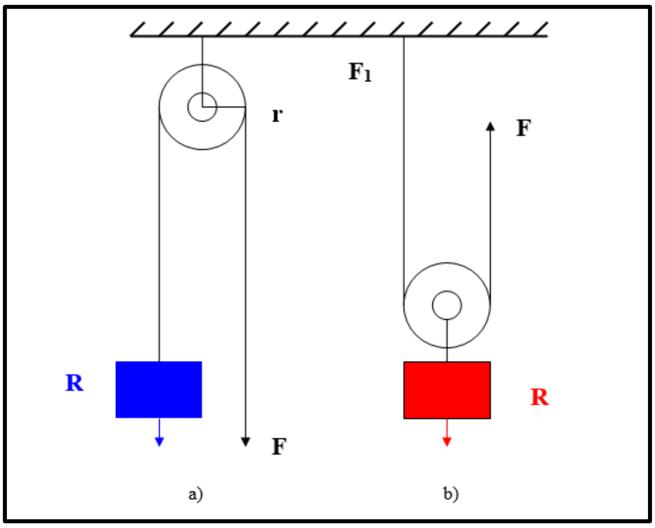

**Figure 1.** Fixed (a) and mobile (b) pulleys.

achieved, or changes the direction of force to balance a resisting force. By design, the pulley spindle will be smaller than the diameter of the metal disc so that the pulley can rotate easily. Therefore, the force required to rotate the pulley (resistive force, which is lost) is small and the tension in the wire on either side of the pulley is practically the same. In practice there are ***simple pulleys*** and ***pulley systems (hoist)***. Bearing pulleys are particularly high performance, with efficiency almost equal to 1. They are, however, considerably more expensive than those with a camp. Bearing models can withstand intensive use at very high speeds without suffering from wear.

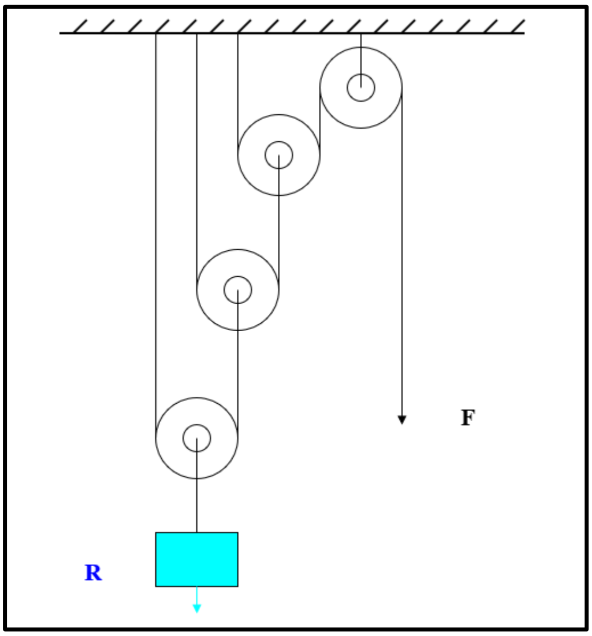

**Figure 2.** Exponential hoist with three pulleys.

***Simple pulleys*** can be:

The ***fixed* pulley** (fig. 1 a), has the shaft clamped in a rigidly fixed fork. At equilibrium, the moments of the forces (with respect to a shaft) acting on the system are equal:

$$F * r = R \times r; \qquad (1)$$

where,

$F$ is the motors (traction) force;
$r$ – radius pulley;
$R$ - resisting force.

Neglecting frictional forces and cable stiffness, the active force $F$ is equal in mode to the resistive force $R$.

The fixed pulley is mainly used to change the direction of application of a force to be overcome for the displacement (usually vertically or horizontally) of a body.

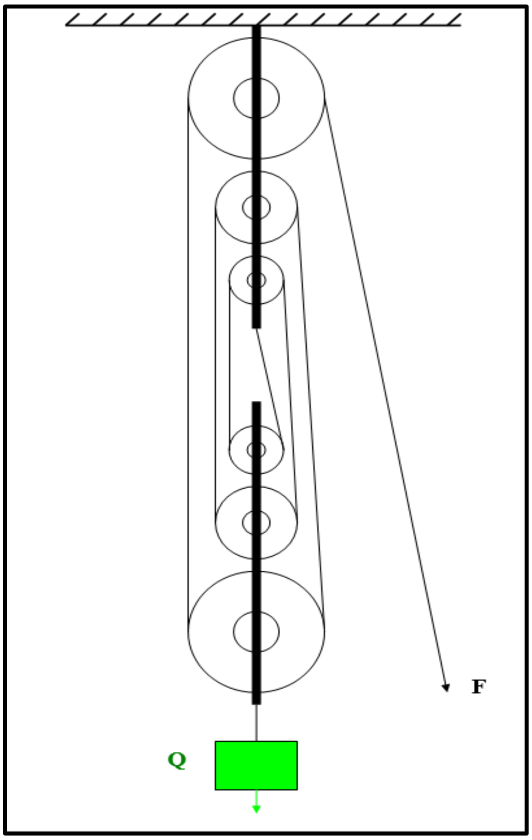

**Figure 3.** Six pulleys factorial hoist.

Mobile pulleys (fig. 1b) has a movable axle from which the weight to be lifted or moved is suspended. At equilibrium, the moments of the forces with respect to the end of the pulley opposite the active force are equal:

$$F * 2r = R \times r; \qquad (2)$$

where,

$F$ is the motors (traction) force;
$r$ – radius pulley;
$R$ - resisting force.

Neglecting frictional forces and cable stiffness, we have the relation:

$$F = \frac{R}{2} \quad [N], \qquad (3)$$

In this way an economy of force is achieved.

**B**. **Pulley systems (hoists)**, are combinations of fixed and mobile pulleys that aim to benefit from both the advantage of reduced driving force (offered by mobile pulleys) and the advantage of changing the working direction of the resisting force (offered by fixed pulleys). These systems have a wide application in the oil industry, construction industry, in transport and lifting machines, as well as in various traction systems. The most common pulley systems are:

**a*) Exponential hoist (muffle)*** (fig. 2), is a pulley system consisting of a fixed pulley and a number of $\boldsymbol{n}$ mobile pulleys arranged in cascade. The lifting or pulling weight, the resisting force $\boldsymbol{R}$, is applied in the centre of the lowest mobile pulley. By applying the driving force $\boldsymbol{F}$ to the fixed pulley, it rotates about its axis and, by means of the cables assembling the system, all the mobile pulleys including the weight $\boldsymbol{R}$ are moved up or pulled. Neglecting friction and cable stiffness, we have the relationship:

$$\boldsymbol{F} = \frac{\boldsymbol{1}}{\boldsymbol{2^n}} * \boldsymbol{G} \qquad [N], \qquad (4)$$

where,

$\boldsymbol{F}$ is the motors (traction) force;
$\boldsymbol{G}$ - weight (resisting force);
$\boldsymbol{n}$ - number of pulleys.

This achieves an economy of force.

The big advantage of the exponential hoist is that it has a very high multiplication coefficient. Its disadvantages are: the relatively large space occupied and the easy disruption during operation (the cable jumps off the pulley channel).

***b) Factorial hoist*** (fig. 3), consists of two pulleys, one fixed and one mobile, each pulley containing an equal number of pulleys mounted on the same fork. If we pull with force $\boldsymbol{P}$ and the bottom muffle goes up, neglecting friction and cable stiffness we have the relation:

$$\boldsymbol{F} = \frac{\boldsymbol{Q}}{\boldsymbol{2^n}} \qquad [N], \qquad (5)$$

where,

$\boldsymbol{F}$ is the motors (traction) force;
$\boldsymbol{Q}$ - load (resisting force);
$\boldsymbol{n}$ - number of pulleys.

This achieves an economy of force.

## 2. Advantages of using pulleys for lifting or towing in transport engineering

The main mechanical advantages of pulleys are:

- Possibility of transmitting high power to the towing/pulling hook (force $\boldsymbol{Q}$ and $\boldsymbol{R}$ presented in figure 1, 2, 3), due to amplification of the pulling moment. The transmission of a large amount of power from one shaft to the other without slipping makes these lifting or towing devices suitable for applications requiring high loads or torque (e.g. lifting or towing parts, assemblies of parts, heavy parts or even machinery and vehicles, etc.);
- Lifting or pulling devices can be operated by means of pulleys at variable pulling speeds directly proportional to the number of pulleys, their diameter and the speed of the driving force (force $\boldsymbol{F}$ presented in figure 1, 2, 3). These aspects allow the angular rotational speed of the pulleys to be matched (adjusted) to the diameter of each pulley and give the pulley assemblies a high degree of flexibility in their applications where a reliable and precise speed variation is required;
- They have a quiet operation (no high noise). This type of transmission does not produce noise in operation, compared to other transmission systems (gears in gearboxes or gearboxes, drive belts, chains, cardan shafts [9], [10], transmission rods and couplings, ropes, cables [11, p. 459], [12, p. 180], etc.). This makes them easily adaptable to working environments where noise is a critical, determining factor;
- hey have a simplified maintenance system with easy, inexpensive maintenance and repair compared to other transmission systems. Because of this, there is no need for constant lubrication or frequent adjustments. This reduces long-term maintenance costs, increasing the reliability of the systems in which they are used;

- They have a longer service life compared to other transmission systems, due to their simplistic construction and operation without friction force.

## 3. Determination of the transmission ratio of pulleys *(i)*

Determining the gear ratio ***(i)*** of the pulley or hoist configurations is very important for determining the load on the tow hook of the towing system or implement. The transmission ratio ***(i)*** of the pulleys determines the speed-power ratio characteristics of the assembly consisting of one or more pulleys. Figure 4 shows the calculation of the transmission ratio ***(i)***, which is determined by the product of the numbers 2, 5 and 9 ***(i = 2 * 5 * 9 = 90)***. The numbers 2, 5 and 9 in the relation represent the number of cables in the sections of planes ***a-a, b-b, c-c***. As an application in transport engineering of pulley systems, where the transmission ratio is determinant Figure 5 shows the scheme of towing a defective vehicle with a simple hoist. The transmission ratio in this case is: ***i = 5***, and figure 6 shows the scheme of towing the same vehicle by means of the compound hoist. The transmission ratio in this case is: ***i = 2 * 3 * 5 = 30***. In practice there are pulley or hoist systems which have a much higher transmission ratio ***(i)***.

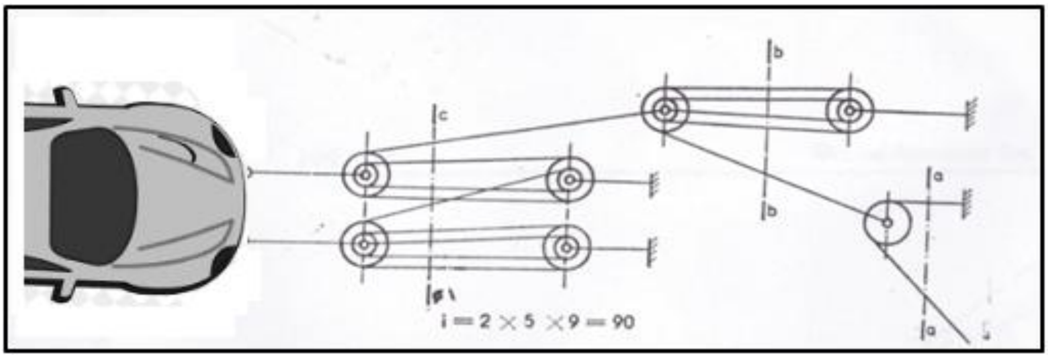

**Figure 4.** Determining the transmission ratio *(i)* for a pulley system when towing a damaged (defect) car. *i = 2 * 5 * 9 = 90.*

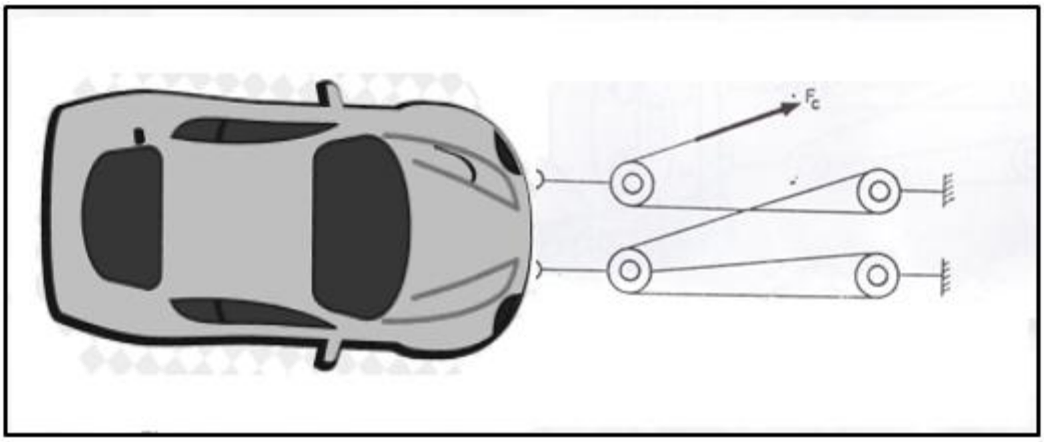

**Figure 5.** Tracking a damaged (defect) car using a simple hoist. *i = 5.*

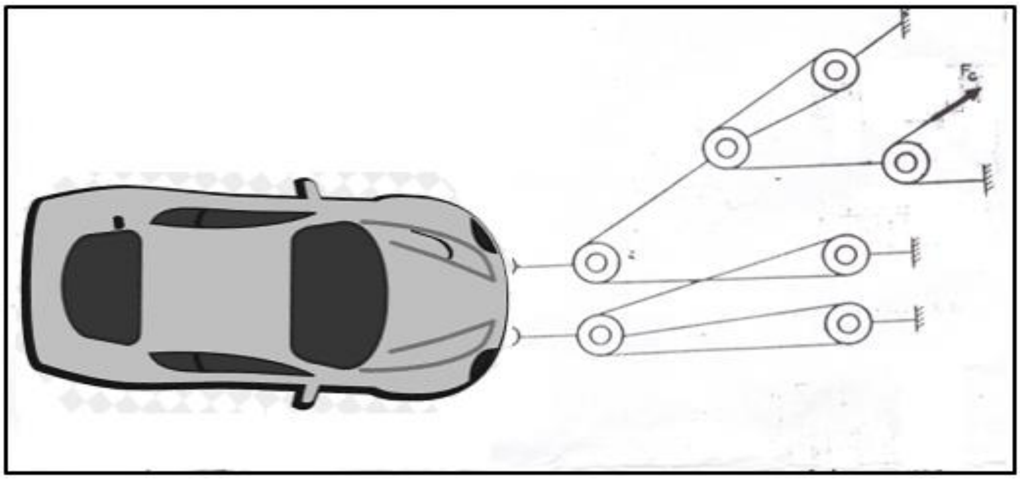

**Figure 6.** Tracking a damaged (defect) car using a compound hoist. *i = 30*.

Based on the above, figure 7 shows the possible schemes of complex hoists used for different forms of towing/pulling hook traction and their transmission ratio ***(i)***.

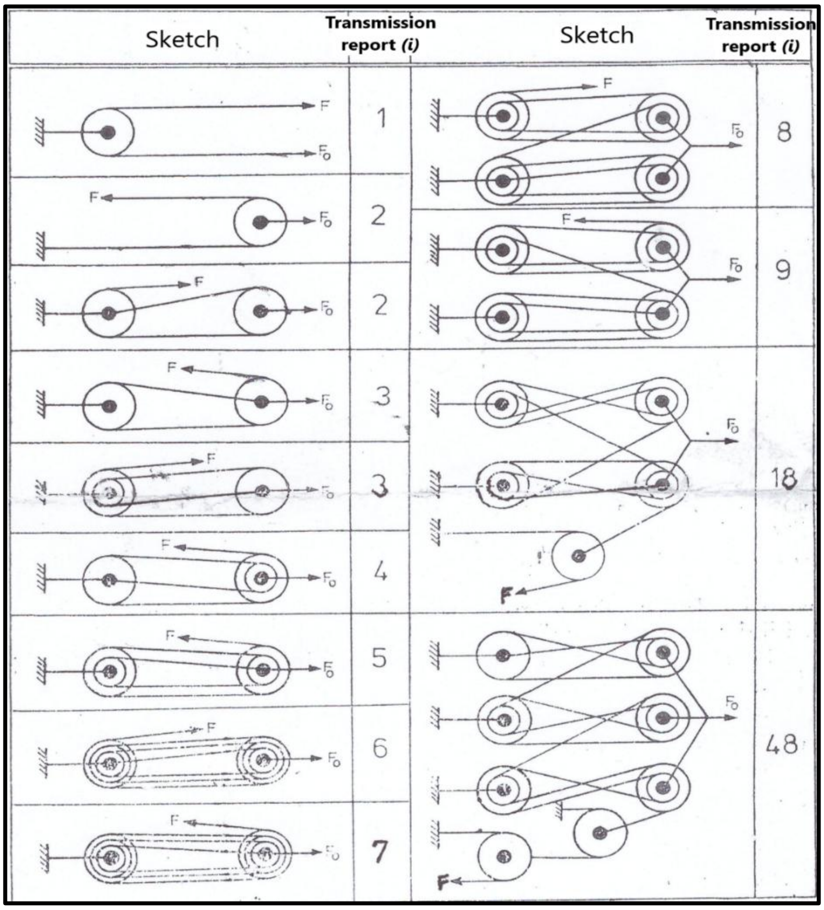

**Figure 7**. Possible layouts of complex hoists used for different forms of towing hitch traction and their transmission ratio *(i)*.

From the analysis of the data shown in figure 7, it appears that the gear ratio ***(i)*** becomes more complex depending on the configuration and number of pulleys used in the towing/pulling or lifting scheme.

## 4.Results and discussions

### *4.1 Presentation of the device for towing and boarding vehicles (motor vehicles)*

In order to highlight the applicability of pulleys, hoists and inclined planes in transport and traffic engineering, a device for towing and loading of rough terrain vehicles was developed (figure 8), consisting of an experimental stand made up of a panel with dimensions: ***L = 1,380 mm*** and ***W = 560 mm***, on which a ramp is mounted, the inclination of which is adjustable forming variable angles **($\alpha = \Delta^{o}$)** with the surface of the panel, which can take values from ***0º*** to ***22º***. The inclination of the ramp is used both to simulate the ramp required to load the equipment onto the trailer and to increase the resistance force when the vehicle moves forward on the inclined plane. The dimensions of the ramp are ***L = 1000*** mm and W = 200 mm, and a miniature vehicle (truck) is towed on its surface. In order to observe how the tractive force changes, the weight of the dummy vehicle can be varied by adding or removing additional weights to its base weight of ***3,300 g***. To adjust the inclined plane, a sliding plate is used to which the ramp is attached at one end. The ramp is adjusted by loosening the nut and sliding the plate to which it is attached up and down.

**Figure 8.** Device for towing and embarking rough terrain vehicles.

**Figure 9.** Graded scale of the experimental model.

The slope of the ramp will be read on the graduated scale in figure 9 which is mounted at the base of the ramp on the panel. Also on the sliding plate there are hooks to which the pulleys will be attached to carry out the experiments. Simple single-roller pulleys with groove diameters of ***35 mm***, ***25 mm*** and ***15 mm***, as well as two and three roller pulley systems (exponential and factorial hoist) are used in the experiments. To achieve the pulling force on the hook, a winch driven by an electric motor supplied at a voltage of ***12 V d.c.*** (electric motor from the windscreen wiper of a Dacia 1300 car) is used, the transmission of the motor torque being achieved in this case by means of a worm gear. The motor speed is adjustable by means of a voltage regulator supplied at ***220 V a.c***. For winding and unwinding the cable on the drum, the winch is controlled by two left and right switches (buttons). Between the pulley system used and the winch, on the cable, there is an electronic digital scale which acts as a dynamometer.

### *4.2 Units of measurement used*

It is known that 1 newton ***(N)*** is the necessary force to impart an acceleration of **$1\ m/s^2$** to a body or object of mass ***1 kg***. For this reason, the newton can also be written: **$(kg * m)/s^2$** [13].
Written in another form, based on the second principle of Newtonian mechanics, which states that the force exerted on a body is directly proportional to the acceleration of that body [14]: **($F = m * a$)**. In this case, ***m*** is represented by the mass of the body having acceleration ***(a)***. In this way 1 newton can

also be described by the units for mass, length and time (the last two units being components of acceleration ***(a)***, in the International System with the relation:

$$\mathbf{1\ N = \frac{kg * m}{s^2}} \qquad (6)$$

A mechanical or electronic dynamometer is usually used to measure the traction force (at the towing hook in our case).

In the experiments we did not have a dynamometer for precise measurements, an electronic scale was used, which accurately reported the measured values in grams ***(g)***.

Conversion from Newtons ***(N)*** to grams ***(g)***: 1 Newton ***(N)*** = 101.972 grams force ***(gf)***.

1 gram force ***(gf)*** = 1/101.972 newtons (***N)*** [15].

Conversion from grams ***(g)*** to Newtons ***(N)***: 1 gram ***(g)*** = 0.00981 newtons ***(N)***.

For example, if the number gram ***(g)*** is 9,800, its newton equivalent number ***(N)*** is 96.105.

Formula: 9,800 g = 9,800/101.97162129779299 newtons = 96.105 newtons [16].

In this case, the following relationship applies [15]:

$$\boldsymbol{gf = \frac{N}{0.00981}} \qquad (7)$$

where,

***gf*** represents grams of force;
***N*** – newtoni;
***0.00981*** – the value to which the conversion relates.

Therefore, to convert kilograms to newtons, the conversion system of units of measurement, specified in Table 1, is used based on relation (6).

**Table 1.** Conversion of units from kilograms [kg] to newtons [N].

| **Mass [Grams]** | **Strength [Newtoni]** |
|---|---|
| 100 | 0,980 |
| 1.000 | 9,806 |
| 10.000 | 98,06 |
| 100.000 | 980,66 |
| 1.000.000 | 9.806,65 |
| 10.000.000 | 98.066,50 |
| 100.000.000 | 980.665,00 |

The conversion from grams ***(g)*** to newtons ***(N)*** was done in this case by mathematical calculation according to the conversion shown in Table 1.

### *4.3 Experimental materials*

- the panel on which the adjustable inclined plane is mounted;
- (vehicle) a towed scale motor vehicle weighing 3.3 kg - 1;
- scale (dynamometer), digital scale with two decimal places - 1;
- roller pulley with a Ø 35 mm roller - 2;
- roller pulley with a Ø 25 mm roller - 3;
- roller pulley with one roller Ø 15 mm - 3;
- factorial hoist with 2 rollers Ø 35 mm, Ø 25 mm - 2;
- factorial hoist with 3 rollers Ø 35 mm, Ø 25 mm, Ø 15 mm - 2;
- hooks for hanging and hanging; wire (rope) for towing.

### *4.4 How to work/experiment*

- The ramp of the device is tilted to a maximum angle of 22º (the ramp used for loading vehicles onto the trailer for transport is raised to the maximum angle at which the adhesion force of the tyres to the track is considered to be lost and where, we can find out what is the maximum resistance of the towed vehicle on the tilted plane);

- Fit the pulley configurations shown in Figures 10, 11, 12, 13, 14 and 15 to the hook on the panel and the hook on the towed/towed vehicle and pull with the electric winch. Read the values on the electronic scale display and convert the readings from kilograms to newtons;
- Set the motor voltage regulator to maximum speed;
- The speed of the system V can be determined by relating the distance the vehicle travels (d) to the time (t) it takes to travel the length of the ramp with the relationship:

$$V = \frac{d}{t} \qquad [m/s] \qquad (8)$$

where,

***d*** is the space/distance travelled by the towed vehicle(s);

***t*** – the time taken to cover the space (distance).

- The mechanical advantage ***AM*** can be calculated with the relation:

$$AM = \frac{Fr}{Fm} \qquad [N], \qquad (9)$$

where,

***Fr*** s the resisting force expressed in newtons ***(N)***, defined by the reaction to the tow hook;

***Fm*** – the driving force expressed in newtons ***(N)***, defined as the force developed by the electric motor.

The mechanical efficiency of pulleys ***(η)*** can be determined. The calculation of the mechanical efficiency ***(η)*** of pulleys is defined by the ratio of the ***useful mechanical work (Lu)*** to the ***consumed mechanical work (Lc)*** using the following mathematical relationships: for a fixed pulley the mechanical efficiency ***η = Lu/Lc*** but, if we take into account the expression of the mechanical work, the relation becomes [17]: ***η = (G1 h)/Fl =(m1 gh)/(G2 l).*** In this case ***G1*** is the resisting force ***(Fr)***, i.e. the weight of the towed vehicle; ***F = G2*** is the active force ***(Fa)***; ***H*** is the distance over which the resisting force ***(Fr)*** travels; l is the distance over which the active force ***(Fa)*** travels; m1 is the mass of the towed vehicle; ***m2*** is the mass of the tractive force (in our case the electric motor of the model, which drives the winch drum). Finally, the mathematical relationship for calculating the mechanical efficiency for fixed pulleys ***h = l*** becomes ***η = (m1 h)/ (m2 l) = m1/m2.*** The ***mechanical efficiency (η)*** of the mobile pulley can be calculated by applying the mathematical relation ***G = 2 ηF***, => ***η = G/ G+2Ff***, aici neglijând greutatea scripetelui mobil.

Figures 10 (a), (b); 11 (a), (b); 12 (a), (b); 13 (a), (b); 14 (a), (b) and 15 (a), (b) show aspects of the experiments carried out and the results obtained.

**Figure 10 (a).** Experiment with a fixed pulley.

**Figure 10 (b).** Result of the experiment with a fixed pulley.

**Figure 11 (a).** Experiment with a mobile pulley.

**Figure 11 (b).** Result of the experiment with a mobile pulley.

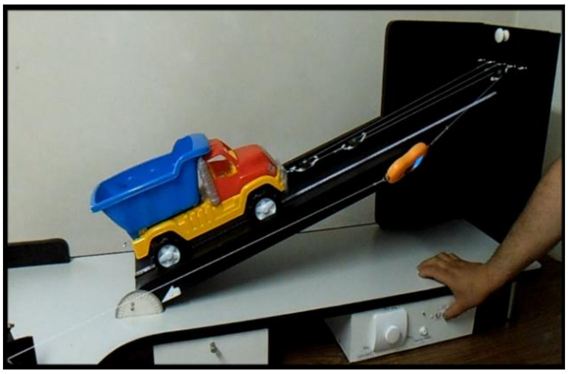

**Figure 12 (a).** Experiment with an exponential hoist (muffle) with 2 pulleys.

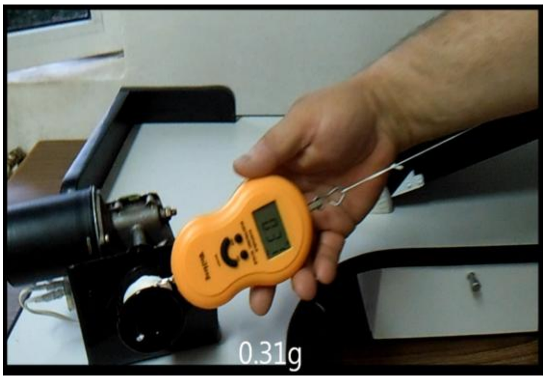

**Figure 12 (b).** Result of the experiment an exponential hoist (muffle) with 2 pulleys.

**Figure 13 (a).** Experiment with an exponential hoist (muffle) with 3 pulleys.

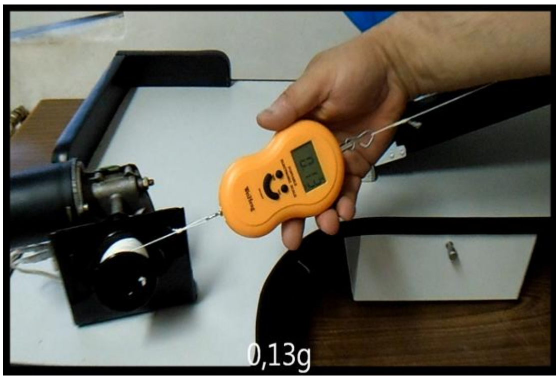

**Figure 13 (b).** Result of the experiment an exponential hoist (muffle) with 3 pulleys.

**Figure 14 (a).** Experiment a factorial hoist (muffle) with 4 pulleys.

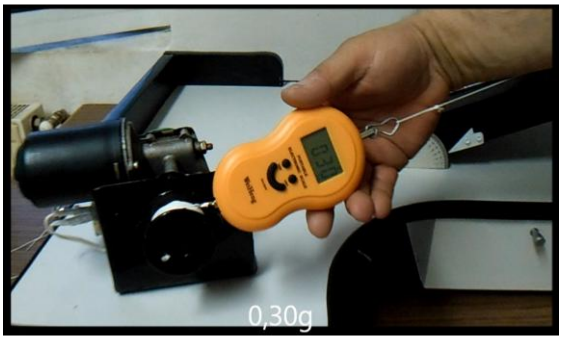

**Figure 14 (b).** Result of the experiment an factorial hoist (muffle) with 4 pulleys.

**Figure 15 (a).** Experiment a factorial hoist (muffle) with 6 pulleys.

**Figure 15 (b).** Result of the experiment an factorial hoist (muffle) with 6 pulleys.

The data from the experimental determinations are summarised in Table 2.

**Table 2.** Centralisation of the results obtained.

| **Traction system configuration** | **Vehicle weight [g]** | **Ramp length (d) [mm]** | **Time needed to walk the ramp [s]** | **$F_m$ [N]** | **$F_r$ [N] (Mechanical advantage on towing hook)** | **V [m/s]** | **AM ($F_r$ /$F_m$) [N]** |
|---|---|---|---|---|---|---|---|
| **Fix pulley** | 3,300 | 1,000 | 6.33 | 0.4 | **11.77** | 0.006 | **29.425** |
| **Mobil pulley** | 3,300 | 1,000 | 10.00 | 0.4 | **0.58** | 0.01 | **1.45** |
| **Exponential hoist (muffle) with 2 pulleys** | 3,300 | 1,000 | 14.00 | 0.4 | **0.31** | 0.014 | **0.8** |

| **Traction system configuration** | **Vehicle weight [g]** | **Ramp length (d) [mm]** | **Time needed to walk the ramp [s]** | **$F_m$ [N]** | **$F_r$ [N] (Mechanical advantage on towing hook)** | **V [m/s]** | **AM ($F_r$ /$F_m$) [N]** |
|---|---|---|---|---|---|---|---|
| **Exponential hoist (muffle) with 3 pulleys** | 3,300 | 1,000 | 19.00 | 0.4 | **0.13** | 0.019 | **0.325** |
| **Factorial hoist (muffle) with 4 pulleys** | 3,300 | 1,000 | 17.00 | 0.4 | **0.29** | 0.017 | **0.725** |
| **Factorial hoist (muffle) with 6 pulleys** | **3,300** | **1,000** | **20.00** | **0.4** | **0.20** | **0.02** | **0.5** |

The data shown in the red coloured column are the results obtained from the experiments of towing the model vehicle on the inclined plane using the configurations of 6 types of pulleys and hoists. The conversion of the results in this column (from grams to newton was done according to the principle shown in Table 1). The analysis of the obtained results shows the mechanical advantage in newtons ***(N)*** of the tractive force ***($F_0$)*** at the towing hook of the vehicle for each type of pulley or pulleys configuration (hoists).

### *4.5 Other applications that can be made with the experimental model*

#### ***a) Measurement of the front approach/withdrawal angle (α) and rear departure/withdrawal angle (β) of the vehicle.***

- ***The front approach/pass angle (α) of the vehicle*** (figure 16) is the maximum angle between the support plane and the tangent planes to the front wheel tyres under static load. It is measured with a graduated protractor between the flat surface of the ground on which the vehicle rests and the lowest part at the front of the vehicle.

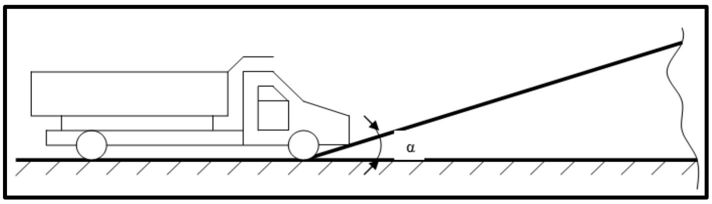

**Figure 16.** Measurement of the vehicle's front angle of approach/traverse (α).

- ***The rear clearance/passing angle (β) of the vehicle*** (figure 17) is the maximum angle between the support plane and the tangent planes to the wheel tyres under static load. It is measured by means of a graduated protractor between the flat surface of the ground on which the vehicle rests and the lowest part at the rear of the vehicle.

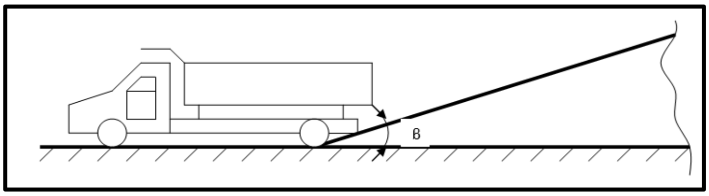

**Figure 17.** Measurement of the vehicle's rear clearance angle (β).

### b) Determination of rear axle (RS) and front axle (RF) reactions of the vehicle.

To determine the reactions of the front and rear axles of the vehicle (figure 18), we have the following data:

- vehicle mass ***(m)*** = 3,300 g;
- vehicle wheelbase (A) = 0.225 m;
- distance from front axle axis to Centre of Gravity = x = 0.080 m;
- distance from rear axle axis to Centre of Gravity = y = 0.145 m;

Knowing the dimensional characteristics of the vehicle/ motor vehicle, one can determine:

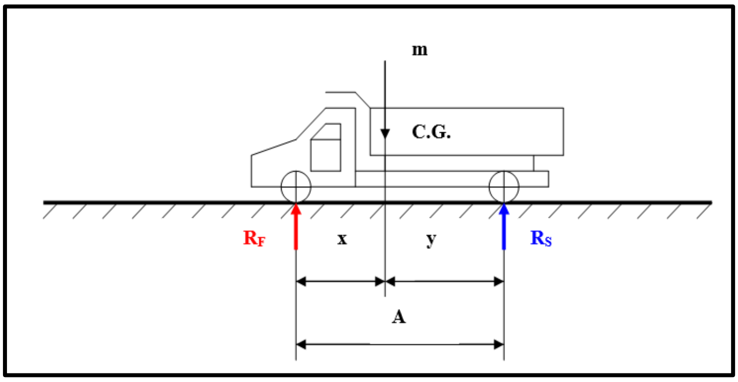

**Figure 18.** Determination of rear axle *($R_S$)* and front axle *($R_F$)* response of vehicles.

*1. Rear axle reaction* ***($R_S$)***

$$m*x = R_S*A; \qquad (10)$$

$$Rs = \frac{m*y}{A} \quad [Kg], \qquad (11)$$

Substituting the known data in relation (10) we obtain the value of the rear axle reaction ***(Rs)*** of the vehicle as follows:

$$Rs = \frac{3{,}300 * 0.145}{0.225} = 2.127 \quad [Kg], \qquad (12)$$

*Note:* The C.G. notation in Figure 18 is interpreted as the vehicle's Center of Gravity.

*2. Front axle reaction* ***($R_F$)***

$$m = R_F * R_S \Rightarrow R_F = m - R_S \quad [kg], \qquad (13)$$

Substituting the known data in relation (12) we obtain the value of the front axle reaction ***($R_F$)*** of the vehicle as follows:

$$R_F = 3{,}300 - 2{,}127 = 1{,}173 \quad [kg], \qquad (14)$$

To determine the reaction of the front axle ***($R_F$)*** a calculation formula similar to relation (11) can be used, as follows:

$$Rs = \frac{m*x}{A} \quad [Kg], \qquad (15)$$

Applying in relation (14) we obtain:

$$Rs = \frac{3{,}300 * 0.080}{0.225} = 1{,}173 \quad [Kg], \qquad (16)$$

### c) Determination of vehicle ramp resistance.

When a motor vehicle travels on a longitudinally inclined road at an angle α with speed ***Va***, the weight of the car ***Ga*** breaks down into two components, one perpendicular to the roadway ***(Ga * cos α)*** and one parallel to it ***(Ga * sin α)***. For the case where a motor vehicle is climbing a ramp, the two components are shown in figure 19. The component parallel to the track

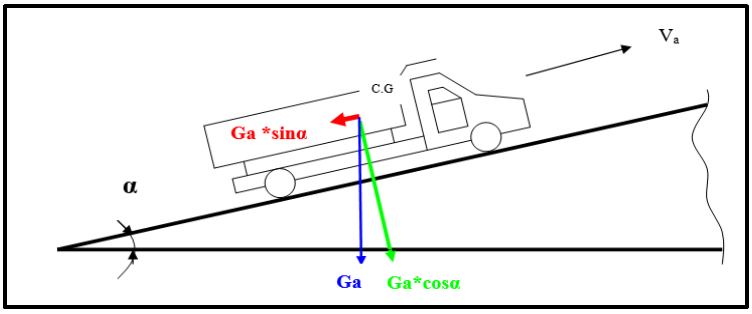

**Figure 19.** Determination of vehicle ramp resistance.

***Ga * sin α*** is precisely the ***resistance to slope displacement Rp*** (ramp up). It opposes the movement of the vehicle in this situation. If the vehicle descends it becomes the ***active force (Fa).***
In this experiment the experimental vehicle will be weighed and the ramp tilted at different angles α (e.g. 5º, 10º, 15º, 20º and 22º).
***Rp*** can be calculated using the following calculation relations:
1. When the vehicle drives up the ramp, $R_p = - G_a * \sin\alpha$; $R_p = - G_a * \cos\alpha$; (17)
2. When the vehicle goes down slope (hill), $R_p = G_a * \sin\alpha$; $R_p = G_a * \cos\alpha$. (18)
*Note:* The notation G.A. in Figure 19 is interpreted as Vehicle Weight.
Table 3 shows the values of sine and cosine angle α as a function of ramp inclination.

**Table 3.** Sine and cosine angle α as a function of ramp inclination.

| Ramp inclination (value of angle α) | Value of sine α | Value of cosine α |
|---|---|---|
| **0º** | 0 | 1 |
| **5º** | 0.087 | 0.996 |
| **10º** | 0.173 | 0.984 |
| **15º** | 0.258 | 0.965 |
| **20º** | 0.342 | 0.939 |
| **25º** | 0.422 | 0.906 |
| **30º** | 0.5 | 0.866 |

*Note:* In Table 3 the α angle values are shown in 5 degree steps.

Knowing the values of the angle α (Table 3), by applying them to the mathematical relations (17) and (18), calculations can be made at the same values of α both when going up the ramp and when going down the slope, to find out the forward resistance of the vehicle.

***d) Tensile forces (T) occurring in traction wires/cables when lifting or boarding defective or damaged vehicles (motor vehicles).***

Calculation of the tensile forces ***(T)*** in the traction cables of the pulley systems is carried out in order to avoid their breaking during traction and to avoid accidents or material damage. At the principle of action and reaction when pulling or lifting by means of pulleys or hoists (exponential or factorial), in the case of bodies connected by cables, ropes (wires) or rods, tensile forces occur within them. Usually the masses of ropes (wires), rods or bars (the sheaves are interposed between the cables), are neglected and are considered inextensible. In this case, even if an acceleration is imparted to them, the force applied at one end is completely transmitted to the other end [18].

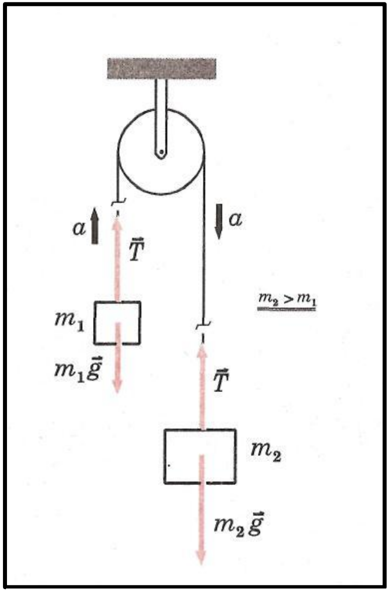

**Figure 21.** Tensile force *(T)* in the wire, in case of a fixed pulley [18].

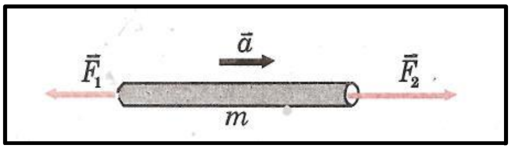

**Figure 20.** Tensile forces *(T)* occurring in cables (wires) [18].

In the following we will present the theoretical part and the calculation relations, on the basis of which the road transport engineer can determine the tensile forces in the traction cables of pulley systems. According to the data shown in figure 20, the acceleration is imparted to the mass cable ***m*** by the resulting forces $F_2 - F_1$ [18]:

$$ma = F_2 - F_1 \qquad (19)$$

Neglecting mass $m = 0$, we obtain [18]:

$$F_2 - F_1 = 0 \text{ or } F_2 = F_1 \tag{20}$$

This forces is called tension in the wire and is denoted by (***T***). The tensile force is transmitted in the inelastic wires.

**I. Wire tensile forces *(T)* for a fixed pulley**

A fixed pulley is shown as in figure 21. The problem to be solved is to find the acceleration and tensile forces ***(T)*** in the wire for this specimen. We point out that in the case of fixed pulleys the bodies move with the same acceleration ***a***. Applying the second principle of dynamics, the system consisting of bodies of masses $m_1$ and $m_2$ moves with acceleration ***a***, in the direction shown, under the action of the resultant forces given in the following relation [18]: $(m_1 + m_2)a = m_2 g - m_1 g$ , results:

$$a = \frac{m_2 - m_1}{m_2 + m_1} g \tag{21}$$

To determine the tensile forces ***(T)*** in the wire (the traction cable), make a *„mental section" („mental cuts")*, in it and apply the second principle of Newtonian mechanics [18]:

$$m_1 a = T - m_1 g \; ; m_2 a = m_2 g - T \tag{22}$$

Replacing the acceleration expression in relation (21) in any of the relations (22), the expression on the basis of which the road transport engineer can calculate the tensile forces ***(T)*** in the ***traction wire/cable***, when using a fixed pulley, with the mathematical relation [18]:

$$\boxed{T = \frac{2m_1 m_2}{m_1 + m_2}} \tag{23}$$

**II. Tensile forces *(T)* in the wire for a mobile pulley**

The simplest mobile pulley system is shown in figure 22. In all cases of mobile pulley systems, bodies move with *different accelerations*. Therefore, *„mental section" („mental cuts")*, are practiced from the beginning. Applying the fundamental principle of dynamics, for each individual body, we write [18]:

$$m_1 a_1 = m\ g - T \;,\;\; m_2 a_2 = 2T - m_2 g \tag{24}$$

Experimentally, it is found that if the body of mass $m_1$ travels a distance s in time t, the body of mass $m_2$ travels half the distance in the same time. So, to the relations (23) we add a relation between the accelerations of the two bodies [18]:

$$a_1 = 2a_2 \tag{25}$$

By dropping $a_1$, and $a_2$ from relations (24) and substituting into relation (25), the expression for calculating ***the tension (T) in the pulling wire/cable*** when using a mobile pulley becomes [18]:

$$\boxed{T = \frac{3m_1 m_2}{m_2 + 4m_1}} \tag{26}$$

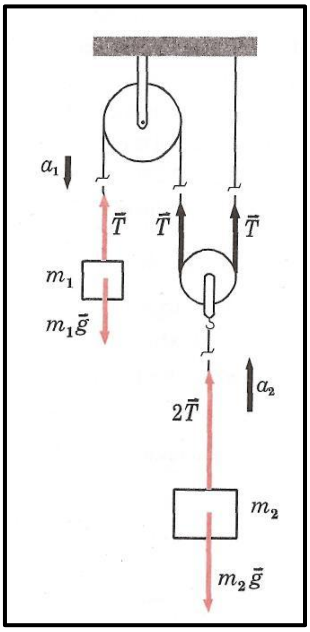

**Figure 22.** Tensile force *(T)* in the wire, in the case of a mobile pulley [18].

The use of the mathematical relationships (23) and (26) will guarantee the accuracy of the calculations and results obtained for the determination of the tensions in the tensile wire/cable when using dummy pulleys, movable pulleys, or exponential or factorial pulley configurations.

## 5. Conclusions

The main objective and the specific objectives of this scientific work have been achieved and also fulfilled by presenting the results of the research carried out in its context.

Due to their simplistic construction and operation, pulleys are most commonly used for lifting heavy loads and transmitting power between axles, in addition to other lifting tools or machinery (jacks, winches, levers, etc.).

The scale model can be successfully used in the laboratories of art and craft schools, high schools or colleges. In this way, students can acquire practical knowledge in car knowledge or road vehicle dynamics laboratories.

This paper accurately presents the results and advantages of the use of pulleys, hoists and inclined plane in the field of transport engineering both in the laboratory, through experimentation, and in real life, when lifting heavy loads or towing damaged or damaged vehicles or vehicles. At the same time, the paper presents the multitude and complexity of other experiments in the field addressed, with applicability in the same field.

Students like to work in teams to discover and acquire new scientific information through the experimental model in order to apply it in a new context by performing functional tasks in real life after graduation. Experimental laboratory activities consistently stimulate their imagination and creativity.

The inclined plane and the inclined plane can also be used successfully in other areas, such as: construction (for transporting or lifting materials, spare parts, organs or machinery from the ground to the upper floors); in recreational play on zip lines or climbing; in cranes; in lifts; in fitness rooms when playing sports, the traditional fountain, the mechanism for raising or lowering a bridge, etc.

By using pulleys, active strength is gained. The fixed pulley gives us the possibility to change the direction of orientation of the active force, we do not have a force gain and we do not lose in distance (ideal pulley). So a fixed pulley gives no mechanical advantage, but it allows a person to redirect the force. So instead of lifting a heavy object directly with arm strength, a human being can use a pulley to lift or pull it. The mobile pulley gives us twice the gain in strength, but we have twice the loss in distance. The same thing happens when using hoists where you gain strength and lose in distance. In the case of hoists, whether exponential or factorial, a much longer cable length is required. Schemes of the pulley or hoist conjugation configurations and their transmission ratios ***(i)*** are presented in this paper.

From the advantages presented in the paper, the specific characteristics of pulleys emerge. They are defined by quietness in operation, do not require consistent oiling, are easy to handle, consistently reduce the force at the lifting/towing hook (there is active force gain), do not have a sophisticated maintenance system and are extremely reliable. The basic proven feature is precision and operational safety.

The determination of the tensiles forces ***(T)*** occurring in the traction cables of motor vehicles in transport engineering is crucial because, exceeding the tensile force moment can lead to the breakage of cables or cables which, under the effect of the existing elastic force, can cause serious accidents with loss of life or significant material damage. This is the task of the road transport engineer, who is responsible for towing or loading the defective or damaged vehicle (motor vehicle) onto the trailer.

The experimental investigations and their methods, through which data and results were obtained in the laboratory, can also be effectively applied in real practice in the road transport industry and beyond, through adequate mathematical calculations in conjunction with the use of corresponding measuring devices or inclined ramps at real scale.

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