# The influence of tyre contact patch and on the stopping distance of automotive vehicles

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**Abstract.** This contribution presents the experimental tests results about the influence of the tyre contact patch on the stopping distance of automotive vehicles. The objective of the performed tests is the evaluation of the effect of tyre inflation pressure, hence the resulting tyre contact patch on the braking system and the brake distance. The conditions of the experiment are a dry and level road surface without steering inputs. To record scientific results, a brake robot system is used. The benefit of a robotic system is the elimination of the interfering variable driver, who is not able to apply the brake system at the same time with the same force. State-of-the-art data acquisition tools are used to log the data.

**Keywords:** Automotive Brake Tests, Tyre Pressure, Rubber Friction, Brake Robot System

## 1. Introduction

Active and passive safety systems in cars is an important topic in automotive research and development. Active safety systems try to prevent accidents where passive systems are designed to reduce the impact of a crash. The ABS is an example for an active safety system while a seat belt tensioner represents a passive system. The linking of active with passive system components enables a complete event sequence, beginning with the warning of the driver about a critical situation till the automatic emergency call after an accident. At present the real contact point of the braking force, the area of contact between tyre and road surface is not well represented in current systems and developments. The physical process in the contact area, called tyre contact patch, is extremely complicated and is described by the physical phenomena of rubber friction. The rubber friction is a combination of adhesive, cohesive and viscous friction as well as hysteresis. On a dry road surface the adhesive friction is dominant. Detailed analysis of this phenomena shows that the adhesive friction depends mainly on the rubber material, but also on the contact size. At this point the rubber friction differs significantly from the friction between two solid objects where the friction is independent of the contact size. To verify the described physical characteristics and to achieve a better idea of the proceedings in the contact area the described experiments are carried out. The objective of the tests is a better description of tyre behaviour and hence more information for the development of advanced vehicle safety and assistance systems.

## 2. Test equipment

The tests were conducted on the closed runway at Keevil Airfield, UK. In Figure 1 the top view of the test facility is shown, including the areas, marked with red colour, for the brake tests and a cool down track for the brakes and tyres between the test runs [1]. The length of the cool down track is 2500 meters and the track for the braking manoeuvre 500 meters. The runway surface is in good condition, but it has to be considered, that the available friction is higher than on road asphalt.

**Figure 1.** Top view of the test area.

As test vehicle a Ford Focus ECOnetic 1.6 TDCi, second generation was used, fitted with Michelin Energy Saver tyres of the dimensions 195/65 R15.

One of the most important aspects of vehicle braking experiments is applying the brake pedal with the desired force. In general it is difficult for the driver to apply and maintain the brake pedal force at the same time, as well as the requested position. To handle the variation of brake pedal utilization, caused by the human driver, a brake robot system is required. Therefore, the experimental vehicle was equipped with brake robot system supplied by Anthony Best Dynamics. A brake robot system has a considerably better accuracy and repeatability compared to the results of an even experienced test driver.

Figure 2 shows the test results of applying a step load of 400N on the brake pedal. The force must neither fall below 300N nor exceed 500N during the braking period. Only 3 out of 27 attempts of the experienced test driver were successful, shown on the left hand side in Figure 2. On the right hand side the results of the brake robot systems are shown. All 5 attempts were successful and the ideal brake force of 400N is deviated by a maximum of only 30N.

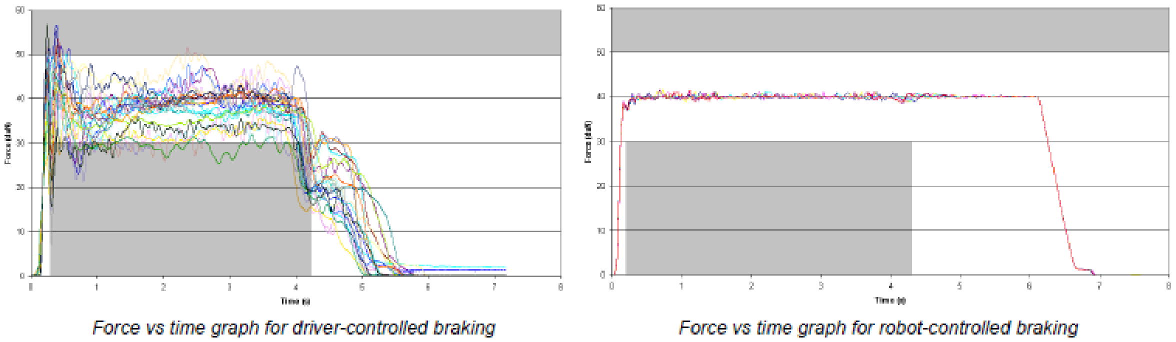


**Figure 2.** Brake robot system vs. experienced test driver [2].

The robot consists of an electrically-driven actuator, which is positioned between the drivers' legs in front of the drivers' seat. The actuator is attached to an adjustable frame, which can be fitted to the drivers' seat. Ratchet straps hold the assembly in place. The robot can apply pedal loads up to 1400N. The maximum velocity is 800mm/s with no load. The force transducer, a strain gauge with a force range of 2kN, is assembled. The accuracy in linearity and hysteresis is +/-0.02% with a proof rating of 3kN [2].

The RT300 Inertial and GPS Navigation System provide outputs of velocity, position and orientation. The system consists of three angular rate sensors, three servo-grade accelerometers and a GPS receiver. The main characteristics of the RT3000 are an accuracy of 2cm for positioning, for velocity of 0.05km/h and for acceleration 10mm/s$^2$ [3].

To measure the contact patch of the tyre, a Prescale film of Fujiflim is used. The Prescale film can precisely measure pressure, pressure distribution and pressure balance. The extreme low pressure film records a range of 0.05-0.2Nmm$^{-2}$ on a resolution of 0.1mm. The film consists of two foils. One foil is coated with a layer of micro-encapsulated color forming material, the second one with a layer of the color developing material [4].

## 3. Test procedure

The objective of the described study is the determination about the influence of the tyre contact size on the stopping distance by experiments with a brake robot equipped with GPS. The tests were performed with an initial speed of 62mph (~100km/h) and the brake manoeuvre is finished as soon as the longitudinal deceleration became zero. The brake pedal force was set to 100N delayed by 0.5s to avoid the influence of ABS. The tyre pressure was changed in 0.2bar steps starting from 2.4 down to 1.0bar. For each applied tyre pressure at least three test runs were conducted, while the temperature and pressure was monitored before and after each run to assure identical conditions. The test vehicle was accelerated over the trigger speed of 62mph. The braking and the data recording were automatically executed as soon as the car slowed down to the predefined trigger. The obtained data is recorded in text files. For data post processing a MATLAB script is written to present and plot the data. To evaluate the tyre contact size, the footprints are scanned and analysed with the software Pixcavator [5].

## 4. The obtained results

The Figure 3 shows the results for the tyre pressure of 1.4bar. Three test runs are performed. The deviation of the car in 'Y' and 'Z' direction is indicated on the left hand side of the MATLAB plot in Figure 3. The xPosition, speed, acceleration and roboter load are plotted against time in extra graphs. The down right graph in Figure 3 shows, that the roboter load is set to 100N, correlating with the constantly decreasing speed in the up right graph. The deceleration is -7m/s$^2$, shown in the left down graph. This plotting is done for each tested tyre pressure.

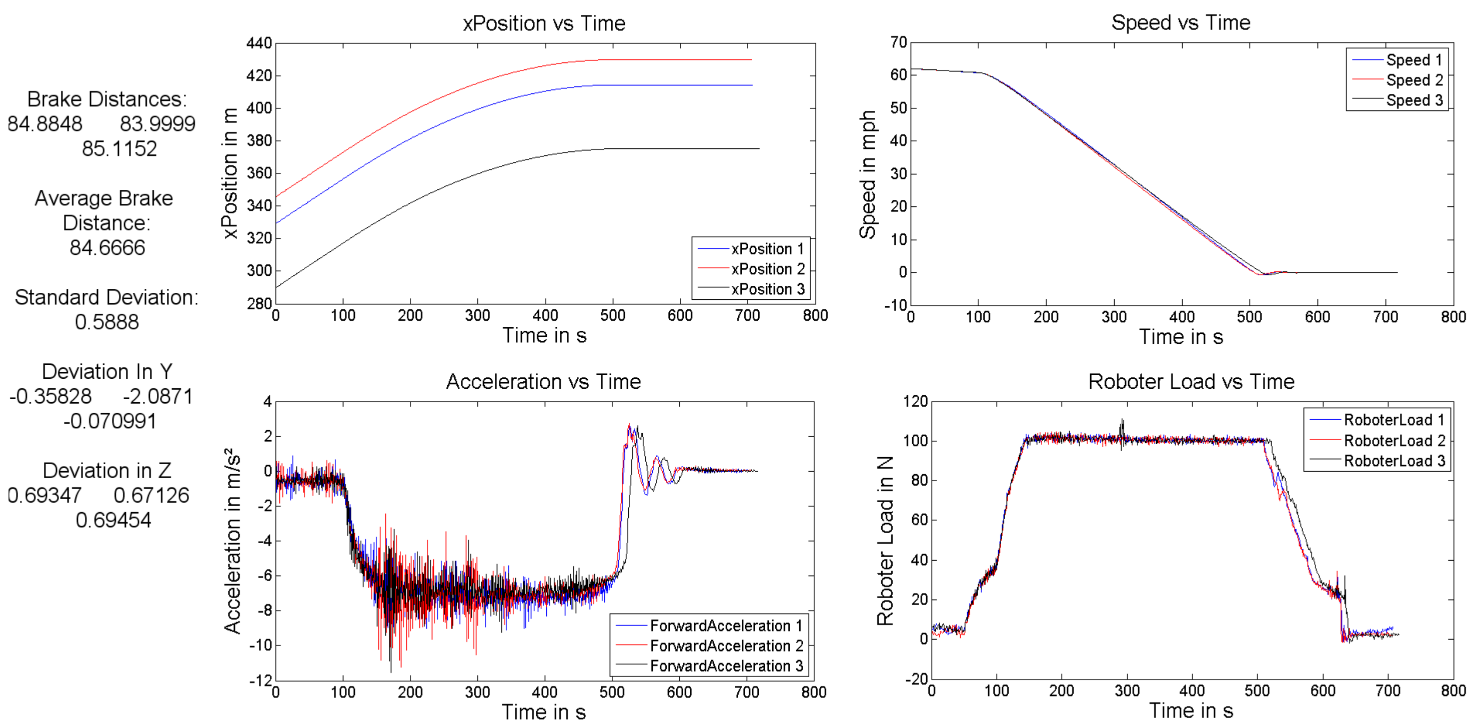


**Figure 3.** Evaluation plot.

Exemplary the tyre footprint for 1.2bar is shown in Figure 4.

**Figure 4.** Tyre foot print at 1.2bar.

## 5. Discussion

The brake distance is calculated with the recorded 'xPosition' and hence the average brake distance. The standard deviation 's' of the measured brake distance is calculated using following expression

$$s=\sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i-\overline{x})^2} \tag{1}$$

where

$$\overline{x}=\frac{1}{n}\sum_{i=1}^{n}x_i \tag{2}$$

and $n$ is the number of elements in the sample [6].

Figure 5 shows the average brake distance graph including the standard deviation.

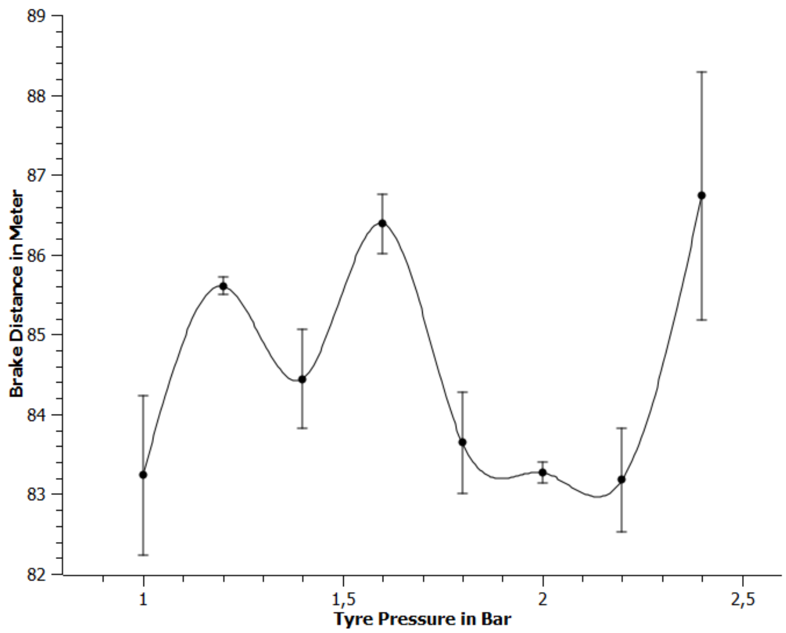


**Figure 5.** Brake distance vs. tyre pressure.

Figure 6 shows the tyre contact size against tyre pressure from 0.5 to3bar. A stable area between 1.8 and 2.2bar can be found.

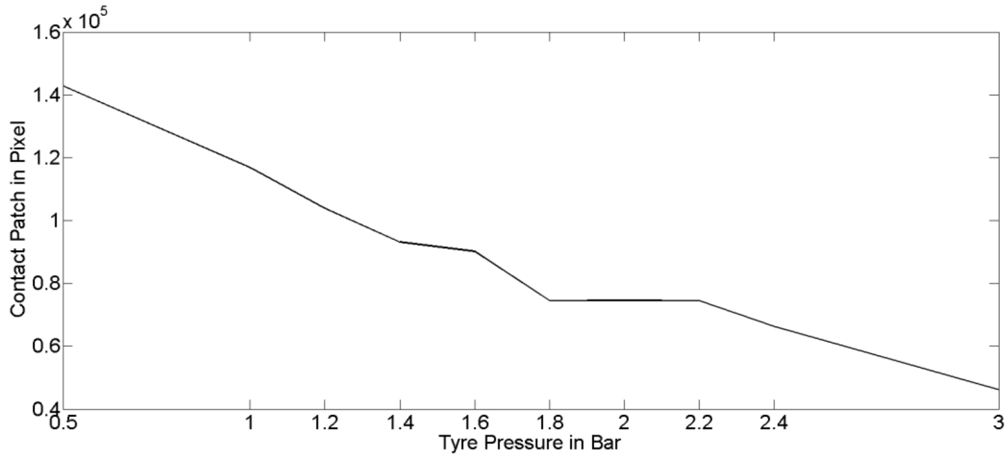


**Figure 6.** Tyre pressure vs. contact patch.

In this area the best stopping distances are achieved and the size of the tyre contact patch stays stable. Beside this area the tyre contact patch increases with high pressure and decreases with low pressure. An explanation of the stable area with the best brake results can be the homogenous pressure distribution in the contact patch.

## 6. Conclusion

Following conclusions can be taken from the tests. The tyre pressure affects the brake distance only slightly on dry road surfaces. But a stable area was detected which gives a better idea about tyre construction and new information for the design of advanced safety and assistance systems. Also it is recommended to drive a car with the suggested tyre pressure of the manufacturer. To verify the findings of a stable tyre pressure area more tests will be carried out in the near future.

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