# THE EFFECT OF WHEEL CONFIGURATION ON VEHICLE COMPONENT TEMPERATURES

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## Abstract

Research on single wide-based wheels, as opposed to dual wheels, on heavy vehicle axles has focused on wear and pavement damage. The influence of single wide-based wheels on the temperature of brake components and vehicle components in close proximity to the brakes has not been investigated. These temperature differences are important as the running temperature of a component affect its durability. Using a test rig running with the two most common dual and single wheel combinations in South Africa, dual wheels with steel rims and single wheels with aluminium rims, the temperatures of the axle bolt, axle beam, brake pads and tyres were measured and compared. The tested brake powers ranged between 5 and 15 kW at a speed of 35 km/h. The results showed that the rate of temperature increase of the dual wheels were at most 5% higher than those of the single wheel. The major thermal difference occurred when the brakes were released; the dual wheel bearing temperatures continued to rise to a maximum temperature 10% higher than those of the single wheels. A simple physical model shows that this difference is because of the dual wheel's higher thermal capacity. This suggests that bearing life on dual wheel axles might be lower than on single wheels if the braking temperatures to which the bearings are exposed reach critical values. The inner tyre sidewall temperature of the single wheel was measured at 18% higher than the inner tyre sidewall of the dual wheel; the measured temperatures were close to the tyre manufacturer's maximum ratings, indicating a higher possibility of tyre blowouts for the single-aluminium wheel.

*Keywords:* Dual vs. Single Wheels, Brake Temperatures, Brake Heating and Cooling

## 1. Introduction

Two of the most common tyre and rim combinations in South Africa are dual tyres with steel rims and single tyres with aluminium rims (see Figure 1). The cheaper and more robust dual wheel option is used for long distance international haulage where compromised security and fewer repair options require transporters to opt for a wheel where a tyre failure will not require the vehicle to stop. Liquid and bulk transporters are more commonly fitted with single wheels with aluminium rims to gain from the weight saving they provide (single aluminium rims are up to 40% lighter than dual steel rims [1, 2]).

From a customer's perspective the practical advantages of each wheel configuration as described above has previously determined the specification chosen for their vehicles, however with ever increasing financial strain imposed on vehicle fleets due to high fuel prices and deteriorating road conditions, it has become critical for transporters to look into the additional benefits of each wheel configuration. With lower axle component running temperatures comes the possibility of longer bearing and brake pad life, lower tyre blowout possibilities and longer overall service intervals for transporters, thus shorter vehicle down-time periods and more importantly; higher mileage for trailers.

Previous research studies into truck-trailer brakes have focused on the difference between disc and drum brakes on brake fade, effect of disc and brake design and materials on brake fade, brake technique (dragging versus pulsing) on braking efficiency etc. [3-7].

The dissipation of heat into the cross flow of air over the brakes and conduction into nearby components along with radiation determine the cooling and heating characteristics of the brakes [8]. By applying the same braking power and speeds to an axle with dual wheels and an axle with single wheels, the effect of each on the temperature of the brake components and bearings can be measured and compared.

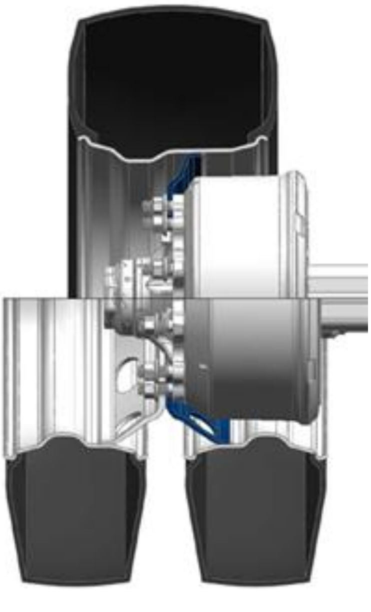


Figure 1: Single vs. Dual Wheels

### 1.1.Objectives

- Measure the rate of temperature increase during braking of truck trailer axles running with dual steel wheels and single aluminium wheels.
- Measure the braking temperatures of components on axles with dual wheels and single wheels.
- Interpret and understand the physics of the above results so as to comment on the advantage each wheel type has over the other with regards to vehicle component life.

## 2. Research Method

A customised test rig was designed and manufactured which allowed an axle with dual wheels or a single wheel to be mounted on a rolling road which could be driven while the brake were continuously applied and the component temperatures measured.

### 2.1.Test Rig

The major test rig components are shown in Figure 2:

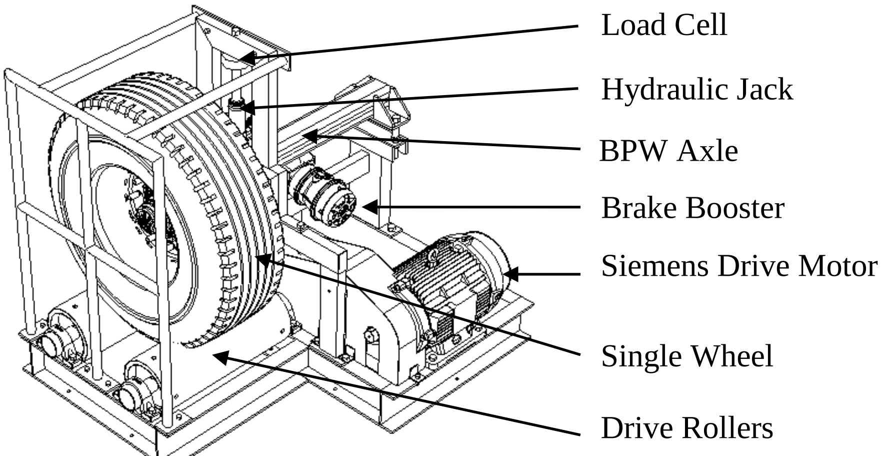
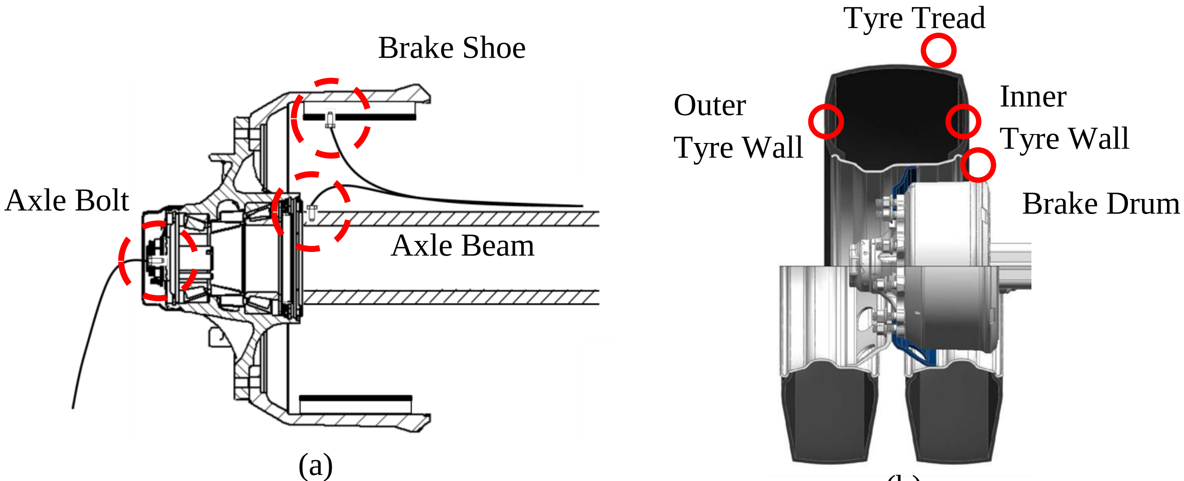


Figure 2: Test Rig Components

Two BPW ECO Plus 2 axles were used, one for each wheel type. The twin drive rollers were powered by a 30 kW Siemens motor to rotate the wheels. A hydraulic jack imposed a wheel load to stop the wheels from slipping on the rollers during braking.

### 2.2. Measured Components and Instrumentation

Three J-type contact thermocouples were used to measure the temperatures of the axle bolt, axle beam and the brake shoe. Figure 3(a) shows a section view of the axle and the location of the thermocouples. A non–contact laser thermometer was used to measure the temperatures of the tyres and the brake drums as shown in Figure 3(b). A load cell was used to measure the wheel load and ensure the value remained constant. The thermocouple readings and load cell measurements were recorded on a National Instruments SCXI DAQ. A sampling rate of 0.5 Hz was used.



(a)

(b)

Figure 3: (a) Thermocouple Locations, (b) Non-contact Laser Thermometer Measurements

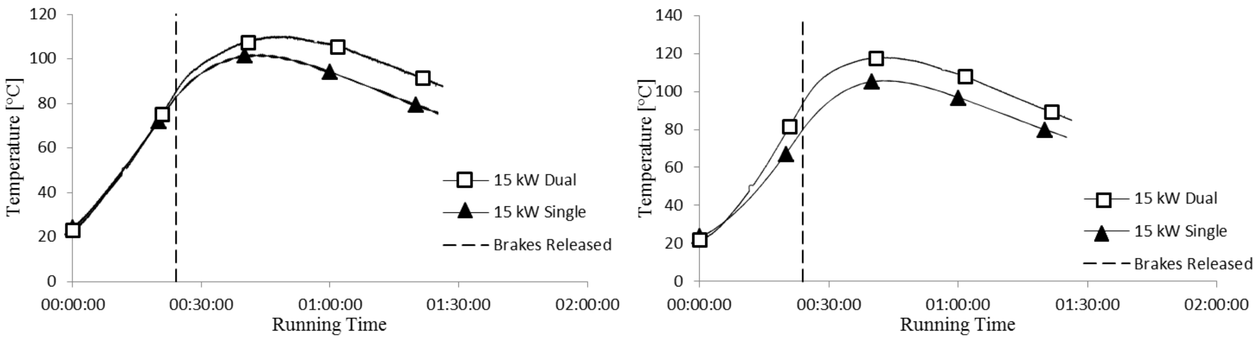
### 2.3.Research Procedure

Both wheel types were driven at 35 km/h and loaded to 3000 kg (representative for an almost fully loaded heavy vehicle) after which the brakes were applied until the additional motor power required reached 5, 10 or 15 kW. The non-contact thermometer readings were conducted every 5 minutes until the brake drum temperatures reached 400 °C after which the readings were conducted every 1 minute. The brake application was limited to 60 minutes or until the brake drum reached a temperature of 450 °C, after which the brakes were completely released and the cooling down phase monitored for an additional 60 minutes.

## 3. Results

Figure 4 and Figure 5 show the thermocouple measurements for the axle bolt and beam and brake shoe, respectively. Only results for the 15 kW test are given as they show the greatest deviation between the two wheel types.

### 3.1. Thermocouple Results



(a)

(b)

Figure 4: (a) Axle Bolt and (b) Axle Beam Temperatures

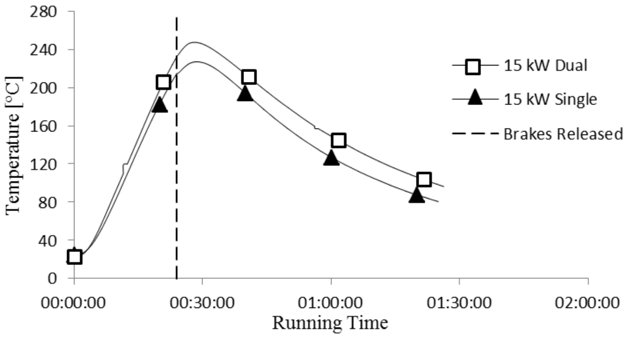


Figure 5: Brake Shoe Temperatures

### 3.2. Laser Thermometer Results

The maximum tyre temperatures that were measured throughout the testing procedure at the tread, inner side wall and outer side wall are shown in Figure 6.

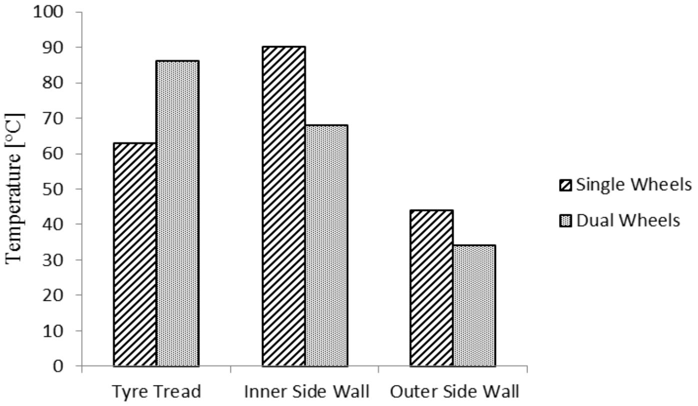


Figure 6: Maximum Tyre Temperatures

### 3.3. Maximum Recorded Temperatures

Figure 7 shows the maximum temperatures experienced by all the measured components.

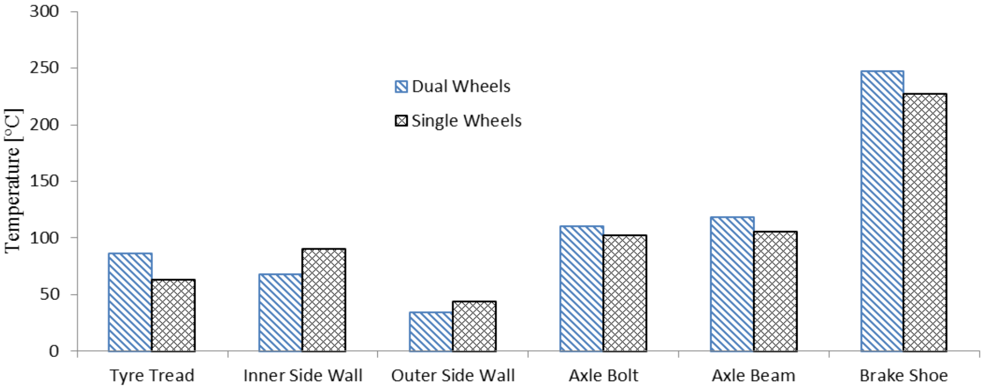


Figure 7: Maximum Temperatures Recorded

## 4. Discussion

### 4.1. Rates of Braking Temperature Increase Comparison

The measured rates of temperature increase of the axle bolt of the dual steel wheels and the aluminium single wheel due to braking were similar (see Figure 4(a)). Once the brakes were released the temperature of the axle bolt of the dual wheels took longer to start cooling and rose to a 10% higher temperature as compared to the axle bolt of the single wheel. The measured axle beam temperature increase of the dual steel wheels was at a 5% higher rate as compared to that of the single aluminium wheel (see Figure 4(b)).

The measured rate of temperature increase of the brake shoes on the dual steel wheels and the aluminium single wheel due to braking were similar (see Figure 5) but the rate of temperature increase on the dual steel wheels was slightly higher than on the axle with the single aluminium wheel.

### 4.2. Component Temperature Comparison and Effect on Component Life

The maximum temperatures (see Figure 7) of all the measured components on the dual wheel axle were hotter than those on the single wheel axle, except for the tyres. The axle bolt temperature (which was in the closest proximity to the wheel bearings) was measured at a temperature 10% hotter on the dual wheel axle configuration as compared to the single wheel configuration. The wheel bearings are a critical vehicle component in terms of temperature management; as increased temperatures can accelerate bearing seizure. Should the durability of any axle component including the wheel bearings be temperature dependent, then the results indicate that these components would have a slightly lower life using dual wheels as compared to single wheels.

With exception of the tread, the temperatures of the single wheel tyre were measured to be higher than those of the duals. The higher tread temperatures of the dual wheels can be attributed to the eccentricity of the re-tread wheels used in the test, which resulted in the tyres being worked. The highest tyre temperature of 90 ºC was measured on the inner side wall of the single wheel tyre. Goodyear states that the tyre bead experiences reduced reliability from temperatures of 123 ºC [9]. Considering 15 kW is not a high braking power expected on trucks (some South African roads require continuous braking powers of up to 30 kW per brake), the possibility of the tyre wall reaching 123 °C exists if high continued braking occurs. The results indicate that should high continued braking occur that the likelihood of a blowout is higher on single aluminium wheels than on dual steel wheels.

### 4.3. Thermal Analysis of the Axle System

#### Difference in Thermal Capacity between the Dual and Single Wheels

An analysis of the physics of the temperature increase of the axle components due to braking can be used to extend the above experimental results e.g. to determine the braking temperatures when using an axle with a single steel wheel. The brakes convert the kinetic energy of the truck into thermal energy at the brake drum - brake shoe interface. This thermal energy is conducted into the surrounding axle components (including the wheel(s)) and dissipated as convection and radiation (see Figure 8).

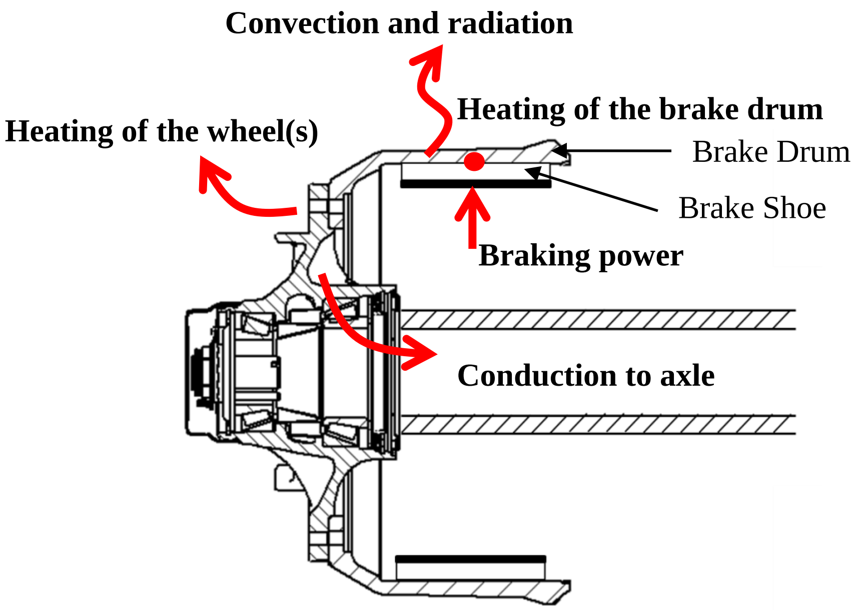


Figure 8: The Dissipation of the Braking Power

The temperature increase of vehicle components in proximity to the brakes is a temporal (time-related) as well as spatial (space-related) problem. The complexity of the problem can be reduced by considering only the lumped temperature of the brake drum and the wheel (see Equation 1).

$$P = C_{pw} m_w \dot{T}_w + C_{pd} m_d \dot{T}_d + \dot{Q}_{cond} + \dot{Q}_{conv} + \dot{Q}_{rad} \tag{1}$$

where $P$ = braking power [W]

$C_{pw}$ = specific heat capacity of the wheel material [J/(kg.K)]

$m_w$ = mass of the wheel(s) [kg]

$\dot{T}_w$ = rate of lumped wheel temperature increase [K/s]

$C_{pd}$ = specific heat capacity of the brake drum material [J/(kg.K)]

$m_d$ = mass of the brake drum [kg]

$\dot{T}_d$ = rate of lumped brake drum temperature increase [K/s]

$\dot{Q}_{cond}$ = rate of heat dissipated through conduction to other vehicle components [W]

$\dot{Q}_{conv}$ = rate of heat dissipated through convection [W]

$\dot{Q}_{rad}$ = rate of heat dissipated through radiation [W]

Equation 1 allows the differences between the single and dual wheel configurations to be studied. The thermal energy stored in the wheel is dependent on the mass ($m_w$) and specific heat of the wheel material. The mass of the dual steel rims is 65 kg while the single aluminium rim weighs 26 kg. The specific heat of the steel rims is 490 J/(kg.K) and that of the aluminium rims is 910 J/(kg.K). Thus the amount of heat stored in the dual steel rims is 31.9 kJ/K while that of the aluminium rims is 23.7 kJ/K. The steel rims have a 26% higher thermal capacity ( $C_{pw}m_w$ in equation 1) compared to the aluminium rims.

The axle bolt temperature (which is the closest temperature measured to the wheel) in Figure 4(a) shows a more sluggish response to the brakes being released with a greater overshoot on the steel rims than on the aluminium rims. This is intuitively consistent with the thermal capacity term ( $C_{pw}m_w$ ) of the steel rims being 26% larger than the aluminium rims as the term in front the derivative is proportional to the time constant in a first order differential equation.

The disruption of the airflow over the brake components is assumed to be larger for the dual wheels than the single wheels, as they cover a much larger frontal surface of the brake drum (as can be seen in Figure 1), thus the convection of heat from the brake drum should be better on the single aluminium rims than on the dual steel rims. This improved convective heat dissipation on the single aluminium rims would appear to be negated by the aluminium rim’s lower thermal capacity and ability to soak or absorb energy.

From the above, it would be argued that a single steel wheel would expect the highest braking temperature increase of vehicle component temperatures as the convection heat transfer of the brake drums is low and the thermal capacity of the wheels is also low.

### Difference in Thermal Conductivity between the Aluminium and Steel Wheels

Aluminium has a thermal conductivity ($k_d$) of 215 W/(m.K) and steel 43 W/(m.K). The cross-sectional areas which conduct the heat are similar for the single aluminium rim and dual steel wheels: one steel wheel has a disc thickness of 12 mm (effective thickness = 24 mm for two rims) compared to the aluminium disc thickness which has a disc thickness 26 mm. The higher thermal conductivity of the aluminium as compared to the steel results in the heat being conducted from the brakes to the tyres five times more effectively on the single aluminium rims. This explains why the sidewalls of the tyres on the single aluminium wheel run hotter than on the dual steel wheels (see Figure 7).

## 5. Conclusions and Future Work

The operating temperatures of vehicle components surrounding the brake system are different on dual wheel axle configurations as compared to single wheel axle configurations. These differences in operating temperature influence the durability of these vehicle components. A custom built test rig was used to test the two most popular tyre and rim configurations used in South Africa namely single aluminium rims and dual steel rims. At a braking power of 15 kW it was found that:

- the maximum temperatures of all the measured components on the dual wheel axle were hotter than those on the single wheel axle, except for the tyres,
- the axle bolt temperature was measured at a temperature 10% hotter on the dual wheel axle as compared to the single wheel,

- the inner side wall of the tyre on a dual steel wheel runs 20 ºC cooler than on a single aluminium wheel, and
- the outer side wall of the tyre on a dual steel wheel runs 10 ºC cooler than on a single aluminium wheel.

The physics to explain the experimental results have been presented as a rough initial model from which it is argued that single steel wheels would result in the axle components running hotter than the single aluminium and dual steel rims. This model needs to be further enhanced and validated with testing to better understand and investigate the effect of using different brake drum materials, brake drum sizes, wheel sizes and changing the spacing of dual wheels.

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