# Enhancing Vehicle Dynamics through Real-Time Tyre Temperature Analysis

**T Stroud[a], KH Du Preez[b], TI van Niekerk[c]**

Received 3 November 2014, in revised form 21 July 2015 and accepted 9 October 2015

***Abstract** Vehicle suspension optimisation is a complex and difficult task, as there are a variety of factors influencing the dynamic performance of a vehicle. During suspension development, the optimisation of a selected few of these factors is often to the detriment of others, as they are all inter-related. In addition, expertise in vehicle setup and suspension tuning is scarce, and is limited to experienced racing teams and large automotive manufacturers with extensive research and development capabilities. With the onset of digital data acquisition, it has become feasible to take real-time measurements of tyre temperatures, to provide information on how a tyre is performing at a specific point on the track. Measuring the tyre surface temperature can provide a useful indication on whether the tyre is loaded equally or not, and what suspension adjustments should be made to improve tyre load distribution. In this research project, the authors focussed on four crucial areas, namely the analysis of tyre operating temperatures, tyre camber settings, tyre pressures and tyre dynamic load distribution. This test data was then used to experimentally determine optimum values for the above parameters, in order to ensure that the vehicle made the best use of the available tyre grip and therefore maximised dynamic performance.*

**Additional keywords:** Vehicle Dynamics, Tyre Temperatures, Real-time Measurement, Automotive Engineering, Formula Student

## 1 Introduction

According to Milliken and Milliken[1] "*Vehicle dynamics is the branch of engineering which relates tyre and aerodynamic forces to overall vehicle accelerations, velocities and motions, using Newton's laws of motion. It encompasses the behaviour of the vehicle as affected by driveline, tyres, aerodynamic and chassis characteristics*". This is a particularly complex subject to study due to the large number of variables at work during the motion of a motor vehicle[2,3]. "*It is about maintaining the maximum possible tyre grip in the appropriate direction, on every part of the track*"[4]. The objective of this research was to develop an objective and repeatable measurement system, which could provide the required data to make reliable inferences regarding the shortcomings of a particular vehicle suspension setup, and provide guidance for potential improvements. The research hypothesis was based on the idea that vehicle tyres, being the sole means of contact between the vehicle and the track, experience all of the forces encountered during acceleration, braking and cornering, and develop heat due to the frictional forces from both the track surface, and tyre internal friction. These temperatures can be used to determine the appropriate suspension adjustments required for best performance.


a. SAIMechE Member, Department of Mechanical Engineering, Nelson Mandela Metropolitan University, Port Elizabeth, trevor.stroud@nmmu.ac.za
b. Department of Mechanical Engineering, Nelson Mandela Metropolitan University, Port Elizabeth
c. Department of Mechatronic Engineering, Nelson Mandela Metropolitan University, Port Elizabeth theo.vanniekerk@nmmu.ac.za


## 2 Research Platform

The NMMU Racing Formula Student[5] vehicle shown in figure 1, is a single-seater racing vehicle designed according to international Formula Student specifications. It is powered by a 600 cc Honda engine, mounted behind the driver for a front/rear weight distribution of 45/55 %. The suspension design employed is a double-wishbone or short-long arm suspension configuration providing accurate control of the wheel movements under all driving conditions[6,7]. Due to its independent nature it also allows tuning of the individual wheel movement and steering geometry.


Figure 1: NMMU Racing Formula Student vehicle "DibaOne"

In this research project two test facilities were utilised for vehicle testing, each selected for their suitability for the required tests, availability, provision of a safe environment to operate the vehicle, and repeatability of track conditions. These two facilities were the Celso Scribante Short Circuit in Schoenmakerskop Road Port Elizabeth, and the Volkswagen South Africa (VWSA) Skidpad in Uitenhage.

Three infra-red temperature sensors (model number: Texense INFKL-150)[8] per tyre were mounted on purpose-built brackets designed to ensure that the sensors consistently focus on a specific area of the tyre while driving. The brackets maintained the recommended 50 mm distance from the tyre[8], which resulted in each sensor measuring a 20 mm wide strip around the circumference of the tyre with a 10 ms response time. Considering the maximum vehicle speed of approximately 100 km/h, and a tyre diameter of 510 mm, a 10 ms sampling rate would result in a minimum of five temperature readings per revolution of the tyre. Lower speeds would result in more samples per wheel revolution. An additional infra-red sensor measured the track surface temperature. As shown in figure 2, three sensors per wheel were mounted inline, so as to record the inner, centre and outer circumferential tyre temperature during vehicle motion.

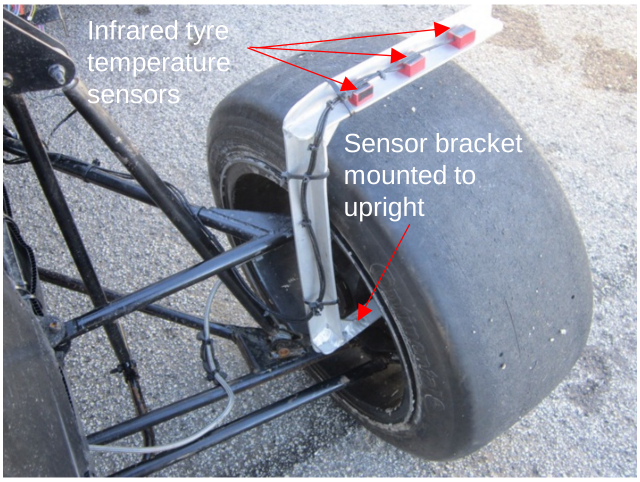


Figure 2: Tyre Temperature Sensor Installation

Figure 3 shows the installation of the test sensors on the NMMU Racing Formula Student vehicle, most notably the three infrared tyre temperature sensors over each tyre. The heart of the data acquisition system was the MoTeC Advanced Dash Logger (ADL3), which combined a comprehensive configurable dashboard display with programmable data logging and control capabilities[9].

## 3 Test Results and Discussion

The test results obtained are discussed in this section, focussing on tyre operating temperatures, the effect of both wheel camber and tyre pressure on tyre temperature readings, as well as the dynamic versus static load distribution on the tyres.

### 3.1 Tyre Operating Temperature

Six different track test warm-up cycles were obtained to provide the results in Table 1, which shows an average of 3.5 minutes to warm up a cold set of tyres by an average of 12.6 °C to their recommended operating temperature of 40 °C. The average track surface temperature was 28.0 °C. Figure 4 shows the average tyre temperatures for all four tyres and the track surface temperature during the warm-up phase of a typical track test. All tyre temperature channels were smoothed using a running average of 3 seconds.

Table 2 shows the average tyre operating temperatures for all four tyres for six different tests, as well as the track surface temperature. The tyre operating temperature on average was 43.0 °C for an average track surface temperature of 27.0 °C.

Figure 5 shows the variation in tyre average temperature over time, illustrating how each of the four tyres experience different operating temperatures. On a clockwise circuit for example, the right hand side tyres may run cooler on average than the left hand side tyres, due to lateral weight transfer, which provides higher loading on the outside (left hand) tyres.

Tyre warm-up can also be accelerated by inducing additional stress on the tyres through weaving on the track, as typically seen before Formula One races, or by driving at higher speeds through the corners, and braking harder. Caution should be exercised when driving on “cold” racing tyres however, as grip is significantly reduced[10], and the vehicle is more prone to unexpectedly over or under steer in a corner. This problem is less pronounced on road cars as road tyres are designed to operate through a much larger range of temperatures and road conditions. Tyre operating temperatures will differ for example, on a track with few, versus a track with many corners, and the data discussed below is relevant only to its specific application. The average tyre operating temperatures were mostly higher than the expected value of 40 °C, as provided by Continental Tyres[11]. On average the recorded tyre operating temperature was 43.0 °C with an average track surface temperature of 27.0 °C.

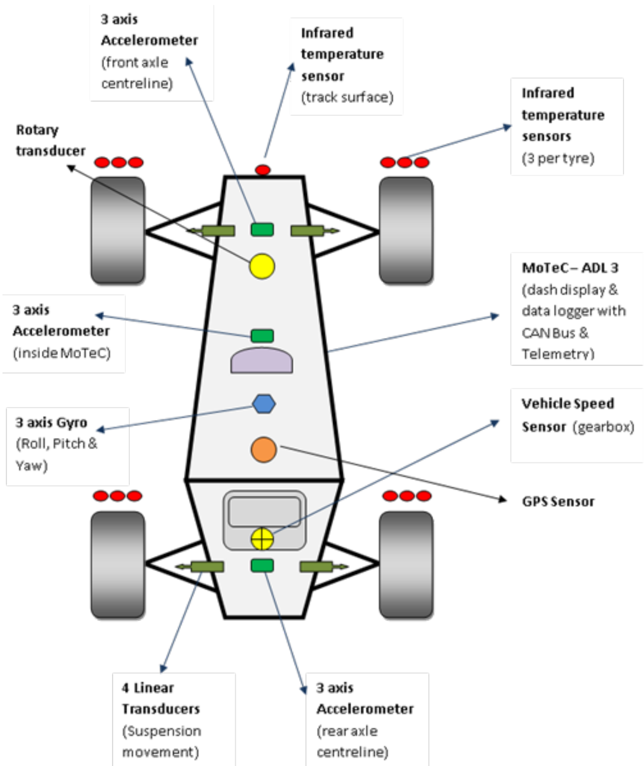


Figure 3: Data acquisition System

Table 1: Tyre Warm-up Test Results

| Test | Time to 40 °C min | Starting Temp. °C | Temp. Increase °C | Track Temp. °C |
|---|---|---|---|---|
| 1 | 4.0 | 29.0 | 11.0 | n/a |
| 2 | 2.8 | 32.0 | 8.0 | n/a |
| 3 | 0.8 | 33.0 | 7.0 | 27.2 |
| 4 | 2.6 | 20.5 | 19.5 | 29.0 |
| 5 | 6.0 | 26.0 | 14.0 | 32.3 |
| 6 | 4.8 | 24.2 | 15.8 | 23.3 |
| Avg | 3.5 | 27.5 | 12.6 | 28.0 |

Ambient conditions played a significant role in this value, with lower track temperatures (23.3 °C) recording lower tyre operating temperatures (39.2 °C). The average tyre temperature of 43.0 °C is 3 degrees higher than the expected value of 40.0 °C, quoted in the Continental Tyre Data[11]. This variance can be attributed to the higher than average weight of DibaOne (330 kg with driver), when compared with other

Formula Student cars who are typically 50-80 kg lighter. This higher mass placed additional load on the tyres, causing them to generate additional heat[4].

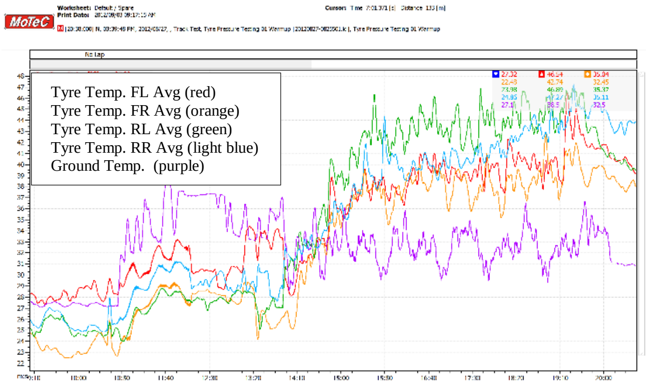


Figure 4: Typical Average Tyre Warm-up Temperatures

Table 2: Tyre Operating Temperatures

| Test | Tyre Average Temp. °C | Track Temp. °C |
|---|---|---|
| 1 | 46.5 | n/a |
| 2 | 43.6 | 27.2 |
| 3 | 41.7 | 27.9 |
| 4 | 45.0 | 26.1 |
| 5 | 42.2 | 30.6 |
| 6 | 39.2 | 23.3 |
| Avg | 43.0 | 27.0 |

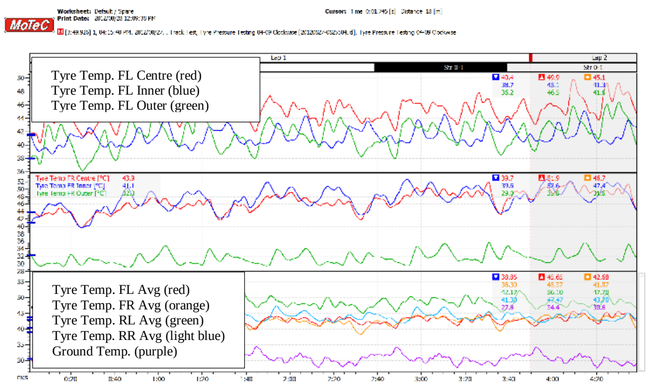


Figure 5: Typical Stabilised Tyre Operating Temperatures

## 3.2 Wheel Camber

Front wheel camber was evaluated in a symmetrical fashion, so that left and right tyre results could be compared to each other during a particular test run. For each camber setting, the results obtained were all averaged from ten laps on the circuit, running clockwise, and then anti-clockwise around the track. Figures 6 and 7 summarise the results of the wheel camber tests with front camber settings of -1.0°, -1.5°, -2.0°, -2.5° and -3.0°, and detailed data is shown in the appendix, tables A1 and A2.

Figures 8 and 9 show the percentage difference between the inner and outer average temperatures, providing a useful indicator of the temperature gradient of the tyre, and how far the static camber setting is away from the ideal. A 0 % indicating the ideal point where the inner and outer temperatures are the same.

The camber test results showed the strong correlation between wheel camber angle and indicated tyre temperatures.

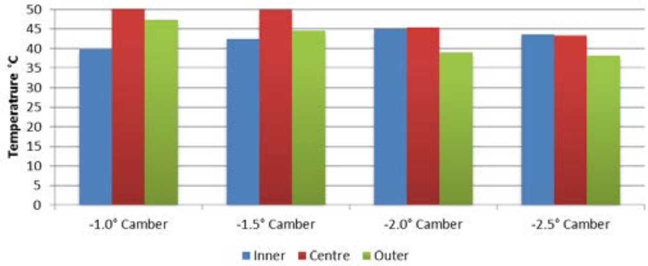


Figure 6: Tyre Temperatures versus Camber Variation – Front Left Tyre

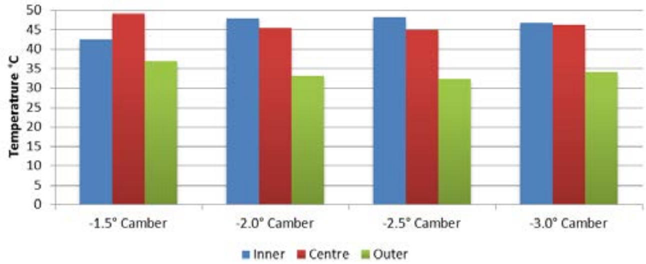


Figure 7: Tyre Temperatures versus Camber Variation – Front Right Tyre

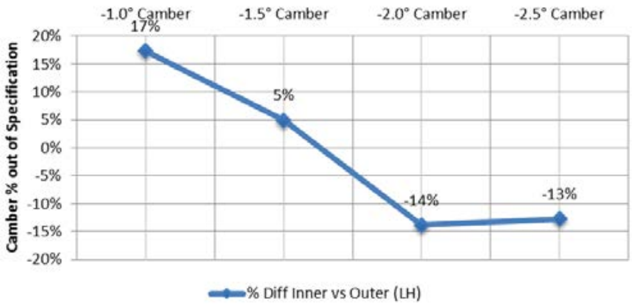


Figure 8: Camber Percentage Indicator based on Temperatures (Front Left)

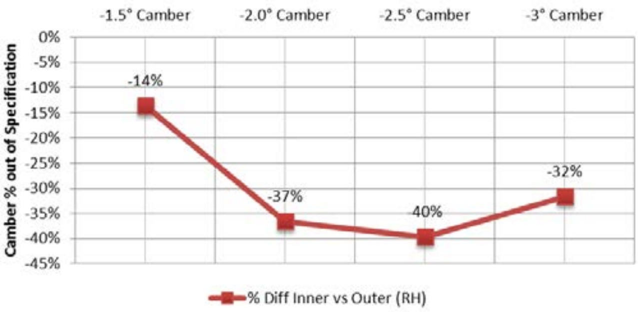


Figure 9: Camber Percentage Indicator Based on Temperatures (Front Right)

Figure 10 shows the simulated[12] wheel camber variation with 30 mm of suspension bump travel, which produced 0.8° of front camber change. For 2° of body roll, the front wheel camber changed by 1.5°. Due to the lack of anti-roll bars fitted to the vehicle, similar levels of body roll were experienced during track testing. The roll centre height, roll axis control and centre of gravity height in relation to the roll centre, also have a significant effect on the amount of body roll experienced in a corner.

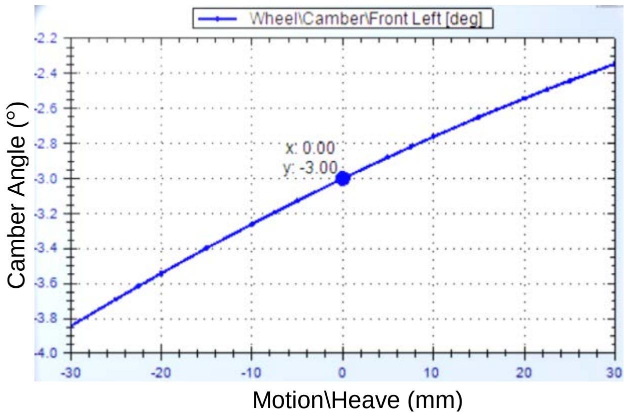


Figure 10: Front Left Wheel Camber Variation in Bump

Dynamic camber variation is produced by steering castor and kingpin inclination angles, further impacting on the wheel camber angle on the track. It is therefore logical to assume a significant camber angle variation on the track when compared with the applicable static camber setting.

The vehicle setup on the digital wheel alignment equipment[13] revealed some inaccuracies in the basic construction of DibaOne, such as differences in left and right wheelbase, compliance in the suspension linkages, which produced uncontrolled wheel camber and toe changes under load, and most significantly a large difference between left and right castor angles. The left castor angle was measured at 3.3°, while the right castor angle was 2.7°, which means a difference of 0.6° between left and right. The problem with this castor variance was that it could not be adjusted out of the vehicle, as it was a fundamental function of the manufacturing accuracy of the suspension A-arms and frame mounting points. The significance of this variance in castor was that even though static camber was set reasonably accurately and symmetrically, dynamic camber would be different between left and right wheels on the track. The higher castor value on the left front steering axis, produced more negative camber on a right turn than the lower castor value would on a right turn. In addition, suspension compliance, previously mentioned, also influenced the results of the wheel camber tests, and for these reasons, the front left and right wheel camber test results were analysed separately.

An analysis of figure 8, which showed data for the left front tyre, revealed that the ideal camber point was between -1.5° and -2.0°, while figure 9 revealed the ideal camber point for the right front wheel to be less than -1.5°. Extrapolating this graph, one could infer that the ideal camber point lay between -1.0° and -1.5°. These differences between the ideal static camber settings for left and right front wheels, rather than being inaccuracy in the data, confirmed the previous assertion that the difference in castor angles produced different dynamic camber levels when on the track. The ideal static camber setting as revealed by the tyre temperature data therefore reflects the need to compensate for this dynamic camber variation between the front left and right wheels. It can therefore be inferred that if the castor angles could be corrected, to a symmetrical value of say 3.0°, the ideal static camber setting would be -1.5°, the average between the recorded values for the left and right wheels.

These static camber test results compared favourably with the Continental tyre data[11] provided to the author by Continental SA, which indicated an ideal tyre camber for maximum grip to be -1.5°, as it revealed the best compromise between lateral force in both lateral directions (towards and away from the camber inclination angle).

## 3.3 Tyre Pressure

Due to the laws for ideal gasses[14], there is a relationship between tyre temperature and pressure, with tyre pressures typically increasing as the tyre carcass temperature increases.

### 3.3.1 Hot versus Cold Tyre Pressure Tests

Tyre pressure settings were done with "hot" tyres, and the first tests performed were designed to establish the relationship between "cold" and "hot" tyre pressures. Figure 11 shows the corresponding hot and cold tyre pressures at two pressure points, namely 90 kPa and 60 kPa. Subtracting the hot pressure from the cold pressure, revealed a difference of 10 kPa on average, indicating a 10 kPa increase in tyre pressure as the tyre temperature increases from a cold to a hot condition.

After an initial cold tyre pressure setting, 10 kPa lower than the required data point, all subsequent tyre pressure readings were done on hot tyres, so as to maintain the temperature generated in the tyre while on the track

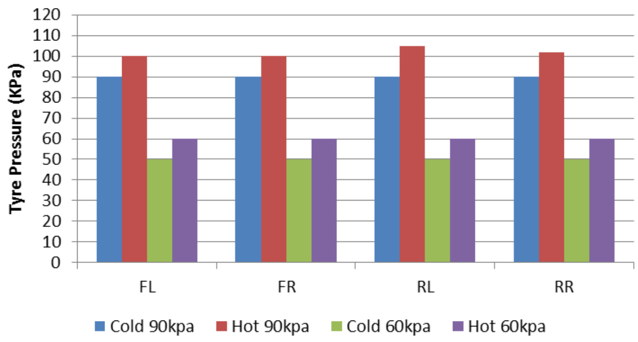


Figure 11: Hot vs Cold Tyre Pressure

### 3.3.2 Tyre Pressure Setting Tests

Tyre temperature data for each tyre pressure setting was recorded during five laps of clockwise and anti-clockwise testing, and the results averaged to minimise any track bias in the tyre temperature results. Figure 12 shows graphically the average clockwise and anti-clockwise tyre temperatures for each tyre pressure setting tested on DibaOne. Detailed test data is available in the appendix table A3.

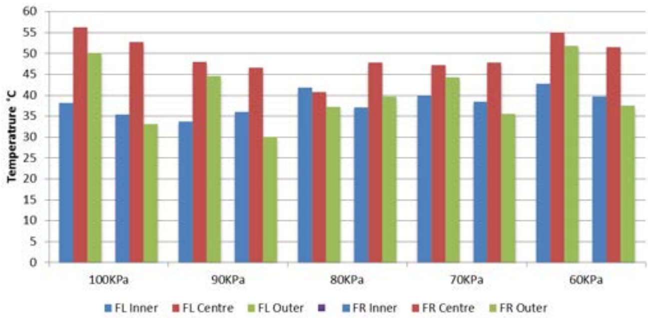


Figure 12: Front Tyre Temperature vs Pressure

Figure 13 shows the percentage difference between the centre tyre temperature and the average of the inner and outer temperatures at hot tyre pressures of 100 kPa, 90 kPa, 80 kPa, 70 kPa and 60 kPa. Although the graph does not reach the 0 % line, it does show a downward trend as tyre pressures are reduced to 80 kPa, and upward trend thereafter. The tyre pressure providing the most even spread of tyre temperatures across the front tyres (inner middle and outer temperatures) is therefore 80 kPa. This is true of both left and right front tyres.

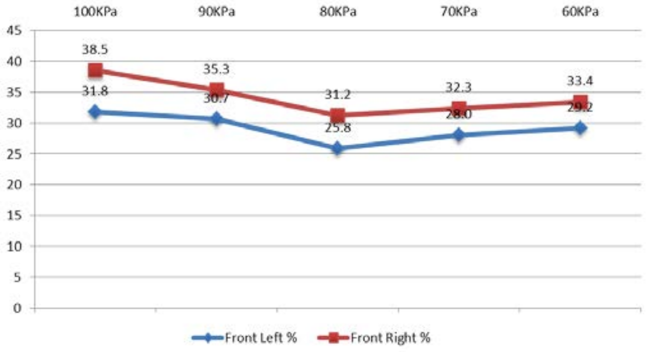


Figure 13: Front Tyre Pressure Indicator

The test results in figure 13 showed an unexpected trend, as the ideal tyre pressure line did not reach the 0 % mark, seemingly indicating tyre over-inflation. Although this result does not conform to general wisdom, regarding the analysis of tyre pressures using tyre temperature data, the lowest point on the graph, where the tyre temperatures were closest to uniform, lay at the 80 kPa level, therefore indicating the most suitable hot tyre pressure, measured at a front static camber of -0.8°. This would correlate to an optimum cold tyre pressure of 70 kPa.

The reasons for this unexpected result can be attributed to the application in which the tyres find themselves, which is a single-seater car on a relatively low-speed (less than 100 km/h) circuit. Typical race car tyre testing would be conducted on racing cars operating at maximum speeds exceeding 200 km/h. These race cars typically run wider tyres with harder rubber compounds than those found on the Continental Formula Student tyre. In addition, the unexpected temperature results for the tyre pressure tests could also potentially be due to the interaction with other factors, such as the unsymmetrical suspension installation, or wheel camber values. The tyre pressure versus tyre temperature tests were therefore a useful, but not as reliable indicator for ideal tyre pressure settings on the car.

## 3.4 Tyre Dynamic Load Distribution

The frictional force required to transmit tractive or cornering forces is proportional to the vertical load on the tyre[15]. For a given tyre and track, it follows that the greater the vertical load on the tyre, the more grip a vehicle will have. The role of the suspension system is therefore to optimally balance the loading at the respective tyre contact patches, while controlling the variation in tyre camber with suspension movement to ensure that the tyre contact patch pressure distribution is optimised[1]. Conant, *et al.*[16] developed an infrared line scanning system to measure surface temperatures of automobile tyres under operating conditions. This experiment demonstrated statistically the individual and interactive effects on tyre temperature profiles, of changes in tyre speed, inflation pressure, and wheel load.

Static versus dynamic load distribution results are shown in figures 14 and 15, where a static load transfer of up to 16 kg was measured due to steering castor and kingpin inclination angles. Dynamic load transfer was measured by comparing the average tyre temperatures and displaying them as a percentage of the total temperature of the tyres, in order to find the portion of the load (indicated by the average tyre temperature) carried by each tyre. The total static weight transfer was calculated to be 16 kg at a maximum steering angle of 24°.

Figure 15 shows a typical dynamic tyre load distribution during track testing by calculating the percentage of each tyre average temperature in relation to all four tyres. The upper window shows the actual average tyre temperatures, while the lower window shows the percentage of each of the tyre temperatures in relation to the sum of the four tyres. This graph is useful to analyse the balance of the vehicle when on the track, and clearly shows that despite setting corner weights before testing, weight distribution is not symmetrical in the vehicle when driving on the track.

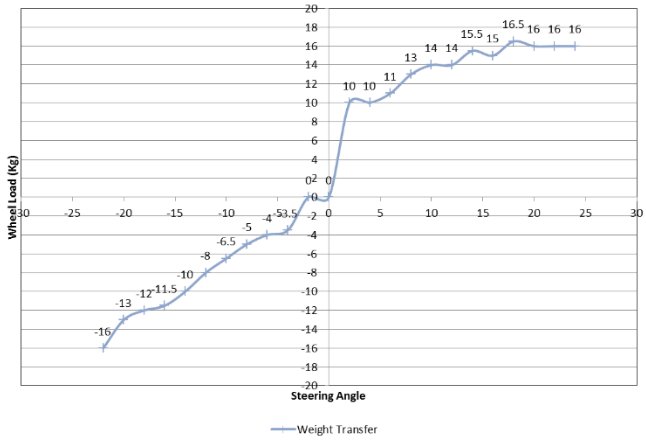


Figure 14: Static Weight Transfer versus Steering Angle

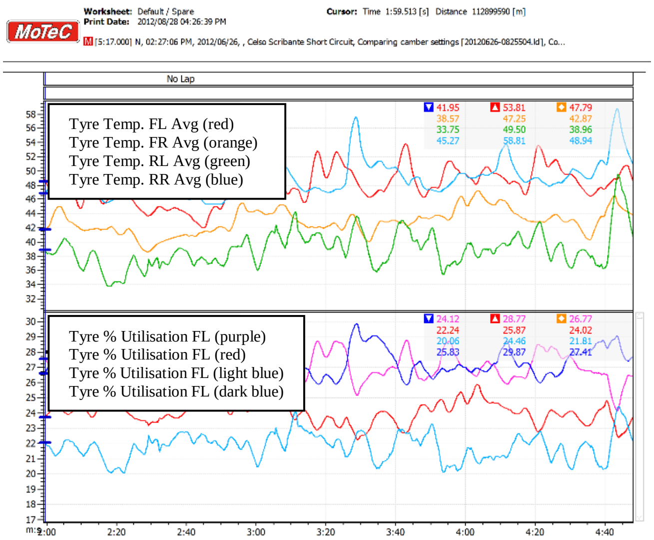


Figure 15: Tyre Dynamic Weight Distribution Based on Temperatures

## 4 Conclusion

The objective of this study was to develop an objective and repeatable measurement system, which could provide the required data to make reliable inferences regarding the shortcomings of a particular vehicle suspension setup, and provide guidance for potential improvements.

Although reduced lap times and “better handling” are the ultimate aim of improving the suspension setup, using lap times as a measurement parameter to evaluate the effect of a particular suspension variable is extremely difficult, due to the vast amount of uncontrolled variables in play. Elements such as driving style, ambient temperature and pressure, wind, engine performance, fuel load, driver weight and tyre wear, can dramatically effect lap times with no change in suspension setup. The authors therefore designed an experiment to focus on the correlation between camber or pressure on tyre temperature distribution with the purpose of detecting a trend that would be useful in pointing out where the “ideal” value lay, for a particular car and track. The data presented clearly illustrates the desired trend, making this method very useful in determining suspension settings experimentally.

During this research project, tyre operating temperatures were determined, along with camber and tyre pressure settings, based on recorded tyre temperature data. In addition, the tyre dynamic load distribution was analysed for the test vehicle providing useful data to enhance suspension setup, and therefore have a positive influence on overall vehicle dynamic performance. A summary of the significant research outcomes are shown in table 3.

Table 3: Research Results for DibaOne

| Tyre Temperatures | |
|---|---|
| Tyre warm-up time | 3.5 min |
| Tyre Operating temperature | 43.0 °C |
| **Camber/Castor** | |
| Front wheel camber angle | -1.5° |
| Steering castor angle | 3.0° |
| **Tyre Pressures** | |
| Tyre pressure increase from cold to hot | 10 kPa |
| Tyre Operating pressure (cold) | 70 kPa |
| **Load Distribution** | |
| Static weight transfer at 24° steering angle | 16 kg |

## References


1. *Milliken WF and Milliken DL,* Race car vehicle dynamics, SAE International, Warrendale PA, 1995.
2. *Clarke P,* Pat’s Corner: Car setup, www.formulastudent.de/academy/pats-corner/advice-details/article/pats-column-car-set-up, 2009.
3. *Smith C,* Tune to win, Aero Publishers, Fallbrook CA, 1978.
4. *Rouelle C,* Vehicle dynamics and data acquisition seminar, Cologne Germany, 14-16 November 2010.
5. 2011 Formula SAE Rules, SAE International, 2010.
6. *Nunney MJ,* Light and heavy vehicle technology, 4th Edition, Butterworth-Heinemann, Oxford, 2007.
7. *Pashley T,* How to build motorcycle engined race cars, Veloce Publishing, 2008.
8. Texense.com, http://www.texense.com.
9. MoTeC, MoTeC ADL3/EDL3 User Manual, V1.1, 2009.
10. *Scarborough C,* Thermal Imaging Cameras Case Study, Racetechmag, 2009.
11. Information about Continental’s Formula Student / Formula SAE tire, 2011.
12. MD Adams 2011, MD Adams 2011 Products, 2010.
13. Longacreracing.com, www.longacreracing.com.
14. *Cengel YA, Boles MA,* Thermodynamics an engineering approach, 8th Edition in SI units, McGraw-Hill, 2014.
15. *Pacejka HB,* Tyre and vehicle dynamics, 2nd Edition, Butterworth-Heinemann, 2006.
16. *Conant F, Hall G, and Walter J,* Surface temperature of running tires using infrared scanning, SAE Technical Paper, 700475, 1970.


## Appendix

Table A1: Front Left Tyre Temperatures

| Camber / Direction | Front Left Wheel | | |
|---|---|---|---|
| | Inner | Centre | Outer |
| -2.0° Clockwise | 42.8 | 45.2 | 40.1 |
| -2.0° Anti-clockwise | 46.9 | 45.4 | 38.0 |
| **-2.0° Avg** | **44.9** | **45.3** | **39.1** |
| -1.5° Clockwise | 41.2 | 53.3 | 49.0 |
| -1.5° Anti-clockwise | 43.7 | 46.6 | 40.2 |
| **-1.5° Avg** | **42.5** | **50.0** | **44.6** |
| -2.5° Clockwise | 41.7 | 42.7 | 38.2 |
| -2.5° Anti-clockwise | 45.2 | 43.9 | 38.3 |
| **-2.5° Avg** | **43.5** | **43.3** | **38.3** |
| -1.0° Clockwise | 38.1 | 53.4 | 49.5 |
| -1.0° Anti-clockwise | 41.4 | 50.9 | 45.1 |
| **-1.0° Avg** | **39.8** | **52.2** | **47.3** |

Table A2: Front Right Tyre Temperatures

| Camber / Direction | Front Right Wheel | | |
|---|---|---|---|
| | Inner | Centre | Outer |
| -2.0° Clockwise | 50.2 | 45.5 | 31.4 |
| -2.0° Anti-clockwise | 45.5 | 45.5 | 34.7 |
| **-2.0° Avg** | **47.9** | **45.5** | **33.1** |
| -1.5° Clockwise | 44.0 | 49.1 | 35.4 |
| -1.5° Anti-clockwise | 40.7 | 49.0 | 38.5 |
| **-1.5° Avg** | **42.4** | **49.1** | **37.0** |
| -2.5° Clockwise | 51.3 | 44.4 | 29.9 |
| -2.5° Anti-clockwise | 45.1 | 45.4 | 34.6 |
| **-2.5° Avg** | **48.2** | **44.9** | **32.3** |
| -3.0° Clockwise | 48.0 | 45.3 | 32.6 |
| -3.0° Anti-clockwise | 45.4 | 47.2 | 35.3 |
| **-3.0° Avg** | **46.7** | **46.3** | **34.0** |

Table A3: Tyre Temperatures vs Tyre Pressures

| | | Front Left Wheel | | | Front Right Wheel | | |
|---|---|---|---|---|---|---|---|
| **Tyre Pressure** | **Direction** | Inner | Centre | Outer | Inner | Centre | Outer |
| 100KPa | Clockwise | 38.1 | 56.1 | 50.1 | 35.3 | 52.6 | 33.0 |
| | **100KPa Avg** | **38.1** | **56.1** | **50.1** | **35.3** | **52.6** | **33.0** |
| 90KPa | Clockwise | 33.6 | 47.9 | 44.5 | 35.9 | 46.5 | 30.0 |
| | **90KPa Avg** | **33.6** | **47.9** | **44.5** | **35.9** | **46.5** | **30.0** |
| 80KPa | Anti-clockwise | 41.7 | 40.7 | 37.1 | 37.0 | 47.8 | 39.6 |
| | **80KPa Avg** | **41.7** | **40.7** | **37.1** | **37.0** | **47.8** | **39.6** |
| 70KPa | Anti-clockwise | 38.6 | 52.4 | 49.2 | 40.0 | 48.1 | 31.3 |
| 70KPPa | Clockwise | 41.1 | 41.9 | 39.3 | 36.6 | 47.3 | 39.6 |
| | **70KPa Avg** | **39.9** | **47.2** | **44.3** | **38.3** | **47.7** | **35.5** |
| 60KPa | Anti-clockwise | 43.2 | 64.7 | 60.1 | 41.3 | 52.8 | 33.7 |
| 60KPPa | Clockwise | 42.1 | 45.3 | 43.2 | 38.0 | 50.1 | 41.1 |
| | **60KPa Avg** | **42.7** | **55.0** | **51.7** | **39.7** | **51.5** | **37.4** |

| | Front Left Wheel | | | Front Right Wheel | | |
|---|---|---|---|---|---|---|
| **Averages** | FL Inner | FL Centre | FL Outer | FR Inner | FR Centre | FR Outer |
| 100KPa | 38.1 | 56.1 | 50.1 | 35.3 | 52.6 | 33.0 |
| 90KPa | 33.6 | 47.9 | 44.5 | 35.9 | 46.5 | 30.0 |
| 80KPa | 41.7 | 40.7 | 37.1 | 37.0 | 47.8 | 39.6 |
| 70KPa | 39.9 | 47.2 | 44.3 | 38.3 | 47.7 | 35.5 |
| 60KPa | 42.7 | 55.0 | 51.7 | 39.7 | 51.5 | 37.4 |