CFD investigation on fully detailed and deformed car tires

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Received on June 26, 2019

ABSTRACT: Approximately 25% of the aerodynamic drag of passenger vehicles is contributed by the wheels. Small features in the tire geometry and the contact area between tire and ground can induce flow separation. Thus, the wheel wake features complex flow phenomena. To understand the appearing flow phenomena, a correct geometry representation of the rotating tire in CFD is essential. The model has to cover the rotating tread, the deformation due to weight and centrifugal forces. Realistic detailed and/or deformed tires are investigated with OpenFOAM® employing a hybrid approach to study the influence of geometrical features on the flow field and coefficients.

KEY WORDS: heat · fluid, computational fluid dynamics, aerodynamic performance, wheel aerodynamics [D1]

1. Introduction

Improving the energy efficiency of vehicles is the major challenge in current’s automotive industry. Reducing the aerodynamic drag is an essential parameter to decrease the energy consumption of combustion as well as electric vehicles. The aerodynamic influence of the wheels on the vehicle is significant. 25% of the aerodynamic drag is caused by the wheels and their periphery [1]. Complex unsteady flow phenomena and large separation regions result from the rotating wheel and the contact with the ground. To understand the complex structures in the wheel wake and their interaction with the vehicle body, many research groups focused their research on wheels and their impact on vehicle aerodynamics. (Wickern et al. [1], Landström et al. [2], Wittmeier [3], Schnepf [4], Haag [5], Lew et al. [6], Hobeika [7] and many others.)

Due to improved computational performance the accuracy of the geometry representation in vehicle aerodynamics simulations is increasing. Despite the huge influence of wheels, the modelling of tires and rims still lacks accuracy in automotive simulations.

The simplest way to model rotating parts is the use of a Rotating Wall Boundary Condition (RWBC). An additional tangential velocity term is implemented on the rotating surfaces. Surface features which are perpendicular to the direction of rotation would need a wall normal velocity term. Conservation of mass though forbids normal velocity components on the perpendicular features. Due to the complexity of tires and rims many surface features would be modelled incorrectly.

Recent studies focused on different simulation methods for the rim like Haag et al. [5], Lew et al. [6], Altmann et al. [8] Hobeika and Sebben [7]. Comparing the RWBC to Multiple/Moving Reference Frame (MRF) and Sliding Mesh (SM) methods showed, that the SM method gives the best results for simulating the rim. Effectively covering the wheel rotation offers further insights into the aerodynamic effects at the cost of high turn-around times [5]. Lew et al. [5], [9] demonstrated the use of SM in OpenFOAM® for generic rims as well as a realistic production rim. Due to these results of rotating the rim in the simulation setup with the SM method is set as the state of the art and a similar workflow to capture the rim rotation to Haag et al. [5], [9] is used in this work.

However, the modelling of the tire rotation is still simplified and different approaches are used to cover the rotation of the treaded tire depending on the simulation code.

The Immersed-Boundary-Method (IBM) can give good results while using the Lattice-Boltzmann Method (LBM). Lew et al. (2017) [6] compares the windtunnel results of a standalone rotating treaded tire by Schnepf et al. [4] with a Lattice-Boltzmann-Simulation. The tire tread is modelled with the IBM. In contrast to a smooth tire with longitudinal grooves the IBM with the modelling of the tread show that high energy air is transported to the boundary layer at the shoulder of the tire. The flow attachment is improved. The average total pressure in the flow field behind the treaded tire is closer to the windtunnel results than for the tire with longitudinal grooves. As described by Lew et al. [8] the IBM is not capable of modelling the tire bulge but the correct height of the rotation axis can be set as an input parameter. Despite the improvement, flow structures near the ground still differ to the windtunnel results. According to Lew et al. [8] the differences are caused by the missing tire bulge in the simulation.

A different approach is proposed by Hobeika and Sebben [7] as well as Altmann et al. [8]. Both use the commercial CFD tool Star-CCM+ and model the tire tread with the MRF method. Therefore, the tire model is split into a SM region for the rim, a Rotating Boundary Wall Condition RWBC for the tire and a MRF volume for the tire grooves. Both achieved good results compared...
to windtunnel measurements and other simulation methods. The MRF method seems to be the most practical method for simulating realistic, deformed tires in automotive applications.

To get matching results to windtunnel tests and for the aerodynamic development of wheels, a good knowledge about the actual tire geometry is essential.

In this paper the MRF method for the tire tread is implemented in OpenFOAM® and first results are discussed. Investigations to the realistic tire geometry are conducted and the influence is evaluated via CFD.

2. Simulation and Experimental Setup

2.1. Simulation Setup

The CFD simulations are performed with OpenFOAM® v1712+ by ESI-OpenCFD. The DDES turbulence modelling with the Spalart-Allmaras RANS turbulence model is used in near wall regions to model the turbulent length scale and the turbulent viscosity. In distant regions from the wall resolving LES turbulence modelling is employed using the Smagorinsky sub-grid scale viscosity model. The accuracy of the used method in comparison to RANS vehicle aerodynamics simulation is stated by Islam et al. [10]. Hybrid wall functions are applied at the walls according to Spalding’s Law [11] due to their applicability in a large range of $y^+$ values.

For the lifted single wheel setup as well as for the single wheel in contact with the ground, spatial discretization is implemented on a finite volume computational domain of approximately 19 million hexahedral cells. The domain is 72 m long, 60 m wide and 36 m high. An automated meshing algorithm was used for the mesh generation. Refinement regions were applied to resolve the wake structures. The minimum cell size has an edge length of $7.5 \times 10^{-4}$ m to resolve the small features of the tire tread. Three prism layers were applied on the geometries with a growth factor of 1.25 and the smallest cell near to geometry with one fourth of the size of the first cell. Figure 4 shows the mesh in the lateral grooves and figure 5 shows the mesh representation in the contact patch. The lifted wheel is set 0.8 m above the ground. For the full vehicle a similar setup was applied resulting in 140 million hexahedral cells.

As typical for industrial aerodynamics applications, large amounts of the turbulence effects are modelled. Furthermore, simulation setups are usually trimmed for stability at maximum Courant numbers above 1 in the need for short turnaround times, as explained by Islam et al. [10].

The Reynolds number based on the wheel diameter as the characteristic length scale is $Re_D = 7.1 \times 10^5$, and a total of 4s physical simulation time is computed. The flow field is initialized by a potential flow solution and each case was distributed to 480 cores.

2.2. Tire modelling

As previously described there are different methods to model rotating geometries in CFD simulations. Investigations on different wheel modelling methods showed that the SM method is the most suitable for rotating rims.

Therefore, the rim rotation is included using the sliding mesh approach with a cylinder annulus-shaped mesh interface region enclosing the non-symmetric part of the rim as seen in figure 1. The mesh interface covering the SM approach for the lifted tire includes only the tread. The reference coordinate system is located in the center of the wheel. The wheel is rotating around the negative y-axis with 1120 rpm according to the free stream velocity.

On the tire shoulder are small labels which have effects on the aerodynamics as stated by Wittmeier et al. [3]. At the selected tire the labels do not feature significant perpendicular faces and are small, compared to the vertical faces of the tire lateral grooves. Therefore, a RWBC is expected to be sufficient. Equivalent to Altmann et al. [8] and Hobeika and Sebben [7] for the tire tread a RWBC is applied and in the lateral grooves the MRF method is used. Besides the lateral grooves, Altmann et al. also include the longitudinal grooves into the MRF volume. In this work, the longitudinal grooves are not included in the MRF volume, due to the fact that they are rotationally symmetric and no vertical features induce energy into the flow.

The investigated tire in the simulation is a Hankook Ventus S1 Evo2 with the dimensions 225/50 R17 98Y. The original tire was scanned in a lifted position. For the simulation the scanned geometry is used to provide the best possible representation of a real tire. The simulation method has to work with scanned tires due to the fact that CAD models of tires are not available and can differ from the produced tires. A smooth tire with only longitudinal grooves was reconstructed from the scanned tire in ANSA, to only cover the effect of the tire contour. For this smooth tire with no vertical faces the RWBC is sufficient to model wheel rotation.

2.3. Dynamic tire deformation

Due to the rotation of the tires, the diameter, the width and as result the shoulder radius change. Schnepf et al. [4] state that it is crucial to capture the tire contour while the tire is rotating. To get the dynamic contour Schnepf applied laser scanners on a special test bench at different sections of the tire and reconstructed the envelope. This method gets the best results and allows a digital
reconstruction. Due to the limited space around the tire in the wheel house this method is quite complicated and an additional test bench is necessary.

To measure the radial expansion and the axial contraction of the tire in a simple way, pictures of the front and of the side of different wheels were made while standing and with rotation. The camera was positioned in the center of the wheel in the side view and on the ground in front of the wheel for the front view. The background was lightened with white surfaces to get sharp contours. To capture an average picture the exposure time was set to 1/6s and therefore, at least three rotations were covered. Different speeds were investigated from 100 to 220 km/h without wind. Measurements with wind showed no influence on the results.

Four different tires were investigated with different aspect ratios to determine the influence of the aspect ratio of the tire. The investigated tires are the Michelin Energy Saver 195/65 R16 92V, the Continental Eco Contact 205/60 R16 92W, the Hankook Ventus S1 Evo2 225/50 R17 98Y and the Bridgestone Dueler H/P 235/60 R18 106H. Except of the Bridgestone all tires were investigated in the Audi windtunnel in Ingolstadt on the 2015 Audi A4 with steel springs. The height of the vehicle was fixed and a tire expansion in radial direction causes a compression of the tire bulge additional to the vehicles weight. On the road the vehicle height is not fixed and the ride height of the vehicle changes without influencing the bulge. The Bridgestone was investigated on an Audi Q7 with deflated air suspension and was therefore not loaded. All tires were filled with a pressure of 2.5bar.

3. Results

3.1. Simulation Results for the lifted wheel

Evaluating the ventilation moment - the shear and pressure forces acting on the wheel generate a counteracting moment to the rotation [12] – for a lifted, rotating wheel should give comparable results between the MRF and the SM method to proof the applicability [7]. To validate the SM simulation method for the lifted tire, it’s compared to a rotationally symmetric, smooth tire with longitudinal grooves. As Haag et al. [9] stated, due to the mesh movement in areas where the mesh rotates in the same direction as the oncoming flow – at the bottom of the wheel – the Peclet numbers become quite small and convergence cannot be obtained in every time step. This problem was solved by adding three additional pressure/momentum coupling steps as proposed and showed by Haag et al. [9] for all simulations of the lifted tire with the SM method for the tread. All cases were simulated with the rim rotating as SM. Differences in the ventilation moment of the rim, as seen in figure 2, result of different flow conditions at the rim caused by the different boundary conditions at the tire. The ventilation moment of the rim in combination with the smooth tire is on a lower level than for the treaded tire.

Comparing the ventilation moment for the SM method with the RWBC gives similar results for the tire with smooth surface and longitudinal grooves (– see figure 2). Also the contribution of the dominant shear forces on the ventilation moment of the tire is closely reproduced (– see figure 3). Both simulation methods feature a small share of pressure forces as expected. Therefore, the applied SM method seems to be valid for simulating the lifted single wheel. Predicting the flow field for a non-rotationally symmetric tire with the SM method should give the most realistic results due to the real mesh movement and can serve as a reference to compare other boundary conditions.

Due to the rotation and the resulting pressure differences in the lateral grooves, an impulse transfer to the fluid in the lateral grooves and therefore an increase in the ventilation moment as well as an increase of the contribution of the pressure forces on the rotating tire is expected.

![Figure 2: Results of ventilation moments for the different tires](image)

Figure 2: Results of ventilation moments for the different tires and boundary conditions.

![Figure 3: Contribution of pressure and shear forces to the ventilation moment of the tire](image)

Figure 3: Contribution of pressure and shear forces to the ventilation moment of the tire – rim excluded.

Compared to the smooth tire the treaded tire simulated with a RWBC shows a reduction in the ventilation moment, as a result of a negative share of pressure forces to the ventilation moment by the grooves, see figure 3. Similar as previous works showed and expected, this method is not suitable for simulating treaded tires. But it shows the influence of the tire tread on the ventilation moment of the used rim compared to the smooth tire. By introducing the tire tread the ventilation moment of the rim increases by approx. 0.25Nm. The tread seems to have quite an influence on the ventilation moment of the rim. This can be an
explanation for different ventilation moments of one rim with different tires.

The results of the SM and the MRF method are very similar in this configuration. Both show an increase in the ventilation moment by 0.5Nm due to the introduced tire tread. The contribution of the pressure forces to the ventilation moment increase and the shear forces decrease (see figure 3). The ventilation moment resulting from the MRF method is slightly higher due to an increased momentum at the rim.

The MRF method seems to be suitable to predict the ventilation moment. Therefore, in comparison with the SM simulation, the velocity in the lateral grooves and the overall flow field is expected to be similar.

Figure 4 displays a cutting plane in the xz-direction at $y = -0.07m$ to display the velocity in the lateral grooves for the different boundary conditions.

Figure 4 a) shows the incorrect representation of the mean velocity on surfaces normal to the rotation by the RWBC. Due to the boundary condition, a wall normal velocity on the perpendicular surfaces of the lateral grooves is missing and the mean velocity in the grooves is low.

Figure 4 b) shows the MRF method for the lateral grooves. As expected due to the rotation, the mean velocity in the lateral grooves approximately equals the rotation speed of the wheel.

Figure 4 c) displays the velocity for $t = 4s$ with the SM method. Because of the mesh movement, a comparable mean velocity representation is in this setup not possible. Despite this, the velocity field shows as expected high velocities in the lateral grooves which are approximately equal to the wheel speed.

The velocity prediction for the MRF case is comparable to the velocity prediction for the SM case and offers an improvement compared to the tire modelling with the RWBC. Hobelka and Sebben [7] achieved similar results for MRF in the lateral grooves compared to SM and RWBC as well as for the ventilation moment. The differences for the single SM time step to the averaged field of MRF result on the one hand due to comparing an averaged field to a single time step and on the other hand due to the fact that the real movement of the geometry to its surroundings cannot be captured with the MRF method, but with the SM method.

The MRF method offers the possibility to simulate a detailed realistic tire in contact with the ground and is therefore an advantage. However, before evaluating windtunnel results and comparing the results to the simulations, the actual tire geometry has to be investigated. Air filled tires deform due to weight and rotational forces and this deformation has to be captured and modelled in CFD to get comparable results as stated by Landstrom et al. [7] and Mlinaric [13].

### 3.2. Simulation results for the wheel with ground contact

The advantages of the MRF method is to work in contact with the ground and with non-circular objects like a tire which is deformed due to the vehicles weight. The modeling of the tire bulge and the contact patch are essential as stated by Mlinaric [13] and Schnepf et al. [4]. Therefore the Hankook Ventus S1 Evo2 was deformed by the weight of a 2015 Audi A4 and 3D scanned.

Additionally, the contour of the contact patch was determined with a scanned silicone paste imprint which was 3D scanned and is displayed in figure 5. With this data the scanned tire and the reconstructed smooth tire with longitudinal grooves were morphed in ANSA to get the best possible representation of the static deformed bulge and the contact patch. The camber of the wheel leads to the asymmetric contour of the bulge. Figure 5 shows the mesh in the contact patch in comparison to the contact patch of the loaded tire. In the displayed 2D picture it is quite
difficult to recognize the end of the flat spot - the contact patch. Therefore, it was highlighted with a dashed red line.

Figure 6 shows the mean pressure distribution in the contact patch for the smooth tire and the treaded tire. The tread leads to a higher pressure in the longitudinal grooves compared to the tire without lateral grooves. This should result in a higher lift coefficient. The low pressure zones at the end of the grooves in x-direction, result from tread wear indicators in the longitudinal grooves and therefore a reduction of the height of the longitudinal grooves and an acceleration of the flow. The higher pressure indicates a reduced mass flow through the longitudinal grooves with a realistic treaded tire and therefore the Jetting should be increased.

Figure 7 displays the isosurface for averaged $c_{p,\text{Total}}$ values equal to 0. It shows the expected wider region of low energy air and stronger vortex formation near the bulge and the contact patch for the treaded tire. This leads to a wider wake region.

The isosurface also shows the formation of smaller vortices on the tire shoulder at the top of the treaded tire, which improve the attachment of the flow on the tire shoulder. This effect was also observed by Lew et al. [6] by using the IBM and really moving the mesh. This improved attachment can be an explanation for the increased ventilation moment of the rim in combination with the treaded tire which was seen in figure 2.

It can be conducted, that the hybrid approach already offers an useful insight in the influence of the tire tread for a realistic deformed tire. But the results require further validation. Therefore, the actual tire contour for a rotating tire and the resulting shoulder radius and contact patch have to be captured.

### 3.3. Dynamic tire deformation

As previously described the radial expansion and axial contraction of the different wheels were measured with an optical measurement method. Figure 8 displays the directions of measuring the deformation. Due to the good lightning of the pictures and the white surfaces in the background as well as the similar camera settings, a subtraction of the standing wheel from

![Fig. 6: Mean pressure distribution in the contact patch in z-normal plane $z = 2\text{mm}$ from the ground for the tire with longitudinal grooves and the treaded tire. The morphed contour is equal for both tires. The displayed pressure is normalized by the density.](image)

![Fig. 7: Isosurface $c_{p,\text{Total,Mean}} = 0$ for the tire with longitudinal grooves and the treaded tire.](image)

![Fig. 8: Results of the optical measurement in the windtunnel at 140 km/h for the Hankook Ventus Evo S1 Evo2: 225/50 R17 98Y Top: Side view, measuring of radial expansion in vertical and horizontal direction Bottom: Front view, measuring of axial contraction.](image)
the rotating wheel shows the increase of diameter as white contour. For the front view a subtraction of the rotating from the standing wheel shows the axial contraction as white line. In this case the pictures at 140km/h were compared to the standing wheel. The radial expansion and axial extension is clearly visible and the extent of the deformation increases with the velocity. Also the radial expansion is not equivalent for the horizontal and the vertical direction. The change of the position of the center of rotation can be measured at the white line at the bottom of the rim.

Figure 9 displays the relative deformation for the different tires for increasing wheel speeds. The rotational forces on the tire increase with square of the velocity. As expected and showed by regression curves with a quadratic polynomial, the deformation increases also with square of the velocity. For the axial contraction the trend lines were set to match the measured points up to 180 km/h. All tires, which were investigated at the Audi A4 with steel suspension, showed that for wheel speeds above 180 km/h the relative axial compression reaches a limit. A reason for this limitation can be the fixed height of the vehicle and the increasing loads on the tires while increasing the wheel speed. The unloaded Bridgestone tire, which was investigated on a car with deflated air suspension and therefore without increasing loads, did not show this behavior.

The Michelin with the smallest width and the highest aspect ratio also showed the largest axial compression and also the biggest tire bulge due to the vehicle weight. Evaluating single pictures, showed that the tire bulge didn’t change in the same amount as the axial compression in the defined measuring plane.

The other tires showed less axial compression and also a smaller bulge. It seems that an increased width and a decreased aspect ratio lead to less deformation.

Additionally, evaluating the data showed a significant change of the width and the height of the longitudinal grooves. The longitudinal grooves reduce the pressure difference between the front and the back of the tire and reduce the Jetting \[14\]. Closing or minimizing the area of the longitudinal grooves can increase the pressure difference and therefore it can increase Jetting effects and the aerodynamic drag. Also the pictures showed that depending on the tire the axial compression is not symmetric for the inside and the outside of the tire. This mainly resulted from the wheel camber.

For the relative radial expansion in horizontal direction the tires behave quite similar, in vertical direction there are bigger differences. The Hankook Ventus nearly keeps its circular contour. For the Michelin Energy Saver and the Continental Eco Contact the relative expansion in vertical direction is larger than in horizontal direction. The contour changes to an slightly oval form. Due to this change, measurements from the front for the top of the tire should be made, which is obstructed in this setup by the vehicle chassis. In accordance to the axial compression the Michelin has a larger relative radial expansion than the Continental. The Continental has a larger relative radial expansion than the Hankook.

The investigation shows that the tire rotation significantly changes the shape of the tires. To estimate the effects on the aerodynamics the measured axial compression and radial expansion were applied on the Hankook Ventus S1 Evo2. The static deformed tire was morphed in ANSA corresponding to the measured deformation. The point where the tire is mounted on the rim is kept as a fix point.
of the tire. The resulting contours for the tire inside are displayed in Figure 10.

The single morphing steps (contours) were simulated as single steps to determine the influence of the parameter change. The results are displayed in figure 11. To cope with the change of the frontal area $c_{DA}$ values were used.

The increase of the diameter has negative effects and the decrease of the tire width positive effects on the $c_{DA}$ values as expected. The combined deformation even reduces $c_{DA}$ more than just the reduced width, despite the increased frontal area. It seems that the change of the shoulder radius, which correlates with changing the diameter and the width, has positive effects on the $c_{DA}$ values as well as the change on the tire bulge and of the contact patch despite a higher frontal area. For the single wheel a correct surface representation seems to be essential. For the wheel in interaction with the vehicle body and the suspension the dynamic tire deformation to rotational forces is expected to have less, but still measurable influence, because of the reduced frontal area facing the air stream. Following Cogotti [15] the radial expansion and the change of the center of rotation should reduce the drag.

The change of the contact patch due to the rotation cannot be measured and only predicted.

The deformed tires were also evaluated at the 2015 Audi A4 with blocked engine bay flow. The whole vehicle was simulated with tires with only longitudinal grooves and with tires with a detailed tread pattern for the static deformation and the dynamic deformation.

The results are displayed in table 1. The overall vehicle drag changes due to the deformation about $\Delta c_D = -0.004$, but the lift increases about $\Delta c_{L,F} = +0.014$ on the front axle and $\Delta c_{L,R} = +0.011$ counts on the rear axle. Implementing the tire tread with MRF for a deformed tire increases the drag by $\Delta c_D = +0.005$ and the lift by $\Delta c_{L,F} = +0.009$ at the front axle and $\Delta c_{L,R} = +0.004$ at the rear compared to the tire with longitudinal grooves (see table 1). Mercker et al. [16] investigated the influence of the tire tread in comparison to smooth tires with longitudinal grooves in the wind tunnel and measured an increase of up to $+0.005$ due to the tread.

Table 1: Results for the dynamic tire deformation and the influence of the tire tread on the 2015 Audi A4 with blocked engine bay flow.

| Configuration          | $\Delta c_D$ | $\Delta c_{L,F}$ | $\Delta c_{L,R}$ |
|------------------------|--------------|------------------|------------------|
| Longitudinal grooves,  | -            | -                | -                |
| static deformed        |              |                  |                  |
| Longitudinal grooves,  | -0.004       | 0.014            | 0.011            |
| dynamic deformed       |              |                  |                  |
| Treaded tire, dynamic  | 0.001        | 0.023            | 0.015            |
| deformed               |              |                  |                  |

Evaluating the flow field showed the biggest influence of the tread of the rear wheels. The wake of the rear tires is wider. For the front tires also a wider wake region and increased vortices near the ground similar to the single wheel in contact with the ground were captured.

The tire tread shows minor differences in the drag values but seems to be essential for predicting the lift coefficients.

4. Conclusions

In the presented work, first results for a hybrid simulation approach for detailed treaded tires were investigated in OpenFOAM®. The hybrid approach - the use of the MRF method for the tire tread and the SM method for the rim - is necessary due to the non-circular contour of tires in contact with the ground. For a lifted circular tire the SM method is applicable for the rim as well as for the tire. The most realistic results are shown by this method. The MRF approach was able to produce similar results for the ventilation moment and the flow field in the lateral grooves for the investigated realistic tire compared to the SM method. Therefore, this hybrid approach should be an efficient way to implement the tire tread in automotive simulations. Still, the relative movement of the geometry to its surrounding and the resulting effects cannot be captured.

Being able to simulate small features like the tire tread and trying to validate the simulation method in future work, makes it essential to model the actual tire geometry in CFD. The deformed tire in contact with the ground showed the influence of the tire tread on the flow around the single wheel. The tread produces larger vortices and a larger wake region near the ground. Also higher pressure and a reduced mass flow in the longitudinal grooves could be observed resulting in an increased drag and lift.
coefficient. At the tire shoulder small vortices form at the lateral grooves improve the flow reattachment at the tire shoulder. The improved reattachment can explain the increase of the ventilation moment due to the lateral grooves which was observed at the lifted tire.

The investigation of dynamic tire deformation showed, that it is essential to capture the actual geometry for all tires. Also for tires with a low aspect ratio, the measured deformation was not negligible. For the whole vehicle the dynamic tire deformation reduced the vehicle drag by $\Delta c_D = -0.004$ and the tire tread increased the vehicle drag by $\Delta c_D = +0.005$. The tread and the deformation showed a larger influence on the vehicle lift and a correct modelling of the actual tire geometry seems to be essential for predicting lift forces.

The tires exhibit a similar deformation behavior and for early stages in the development process it should be possible to estimate the deformation of a new tire by these results. The asymmetric axial and radial deformation, due to the wheel camber and the construction of the tire, showed that it is essential for further work to always capture both sides of the tire and the whole perimeter.

5. Summary and Outlook

This work presents a method to investigate realistic, deformed, scanned tires with the open source CFD tool OpenFOAM®. The MRF method gives promising results for the simulation of the tire tread. Being able to simulate small features like the tire grooves, it is quite essential to understand the aerodynamic behavior of tires. Also a good knowledge about the deformation of the tire geometry due to the weight and rotational forces as well as characteristics of the windtunnel setup is necessary.

In further work, a lot of effort has to be put into capturing a correct tire contour and the contact patch while the tire is rotating. A measurement for the whole rotating tire under vertical load has to be implemented.

If the tire geometry can be modelled in an accurate way the CFD setup will be revised by comparing it to windtunnel tests and using different tires to validate the simulation method.

Acknowledgements

We would like to express our gratitude to our industry partner AUDI AG for their financial support and thank Dr. M. Islam for the opportunity to carry out research. This publication is supported by TUM Graduate School’s Faculty Graduate Centre of Mechanical Engineering.

This paper is written based on a proceeding presented at JSAE 2019 Annual Congress.

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