

Further Analyses on Prediction of Automotive Spinning Wheel Flowfield with Full Width Moving Belt Wind Tunnel Results

Arturo Guzman
FCA US LLC

Young-Chang Cho
Exa Corporation

John Tripp and Kumar Srinivasan
FCA US LLC

ABSTRACT

Pickup trucks are designed with a taller ride height and a larger tire envelope compared to other vehicle types given the duty cycle and environment they operate in. These differences play an important role in the flow field around spinning wheels and tires and their interactions with the vehicle body. From an aerodynamics perspective, understanding and managing this flow field are critical for drag reduction, wheel design, and brake cooling. Furthermore, the validation of numerical simulation methodology is essential for a systematic approach to aerodynamically efficient wheel design as a standard practice of vehicle design.

This paper presents a correlation the near-wheel flow field for both front and rear spinning wheels with two different wheel designs for a Ram Quad Cab pick-up truck with moving ground.

Twelve-hole probe experimental data obtained in a wind tunnel with a full width belt system are compared to the predictions of numerical simulations. In addition to the previous study on a minivan, this paper provides more detailed correlations for a set of new data with two different rim configurations and multiple cross-plane measurements. As a result, the evolution of wheel wake shear layers are three dimensional flow structures are better resolved. The numerical simulations predict the overall wheel wake structures and their changes with different configurations consistently. On the other hand, the flow features with higher discrepancy between the two approaches, such as the wake near wheel contact patch, are also discussed.

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INTRODUCTION

Aerodynamic development of vehicles and specifically wheel designs, require alignment and correlation on the results between CFD simulations and wind tunnel tests. The authors in the previous study [1], showed a comparison of the near wheel flow field of an alloy wheel compared to a wheel with a convex cover on a production minivan, they showed the measured difference between both configurations.

However, the performance of such configurations will change depending on the type of vehicle. The duty cycles between a minivan and a pickup truck are different enough to realize that the tire line up and tire envelopes require a different execution for these vehicles.

Design elements like, a taller ride height, larger tires and envelopes plus off road capabilities will create a different flow environment around the tires.

In this paper, a study is presented on the near wheel flow field generated due to rotating wheels and moving ground effects varying the wheel design.

There are reference of other publications that have focused on documenting spinning tires [2,3,4,5,6], dissimilar to those studies, this paper was performed combining the following details:

1. Having a full width moving belt simulation of the ground underneath the vehicle and tire
2. Utilization of a production vehicle with production wheels and tires.
3. Documentation of the vehicle attitude changes and tire section changes at rest and at speed.
4. Documentation of the tire tread, shoulder, sidewall and section details at rest and at speed.
5. Documentation of the body deformations due to aero loads.

These documented details will then provide an accurate representation of the conditions experienced in the wind tunnel into the CFD simulations.

EXPERIMENTAL APPROACH AND SET UP

Due to the importance of designing wheels with rolling tires and moving ground effects, and to keep consistency with the previous study on the minivan, it was critical to capture the flow field with boundary conditions of the moving road underneath the vehicle. Therefore, the vehicle was tested at the Windshear Rolling Road Wind Tunnel [7].

THE VEHICLE

The vehicle used for this study is a production 2015 Ram 1500 STL 4X2 pickup truck from FCA US LLC, shown in Figure 1. Two different 5 Spoke Aluminum wheels designs were tested keeping common the same tire size and brand. The tire used was the production Goodyear Wrangler SR-A P275/60R20 with standard pressures. The only modification on the vehicle was applied to the driveshaft which had to be disconnected to protect the differential this is standard practice at Windshear.



Figure 1. Ram 1500 in Windshear Wind Tunnel with Wheel design A

The vehicle attitude was set to a condition consistent with the so-called EPA “2 Pass” loading consisting of 68 kg in each front seat and a full tank of gas. Vehicle dimensions are given in Table 1.

Table 1. Vehicle Dimensions

Overall Length	5816.6 mm (229")
Wheelbase	3568.7 mm (140.5")
Overall Height	1922.78 mm (75.7")
Overall Width	2016.76 mm (79.4")
Front/Rear Track	1727.2mm (68") / 1714.1 mm (67.48")
Drivetrain	4X2
Engine	3.6L V-6 / Automatic Transmission
Wheels and Tires	Goodyear Wrangler SR-A P275/60R20 114S
Frontal Area	3.37 m ² (36.35 ft ²)

CONFIGURATIONS

The vehicle was maintained unchanged, the only configurations that were tested on the vehicle were two different wheel designs. Wheel A features 5 spokes and large openings and wheel B with 5 spokes and smaller openings Both wheel designs are shown in Figure 2. For these configuration changes the tire brand, size and pressure was maintained the same to keep consistency.

Vehicle was set to nominal 4×2 wheel lip heights, 919mm for the front and 979mm for the rear at static conditions. Pictures were then taken during the test at rest and at speed to document the tire growth and raise of the vehicle due to aero forces. Figures 3 and 4 show the ride height changes in the front, similar behavior was experienced on the rear of the vehicle.

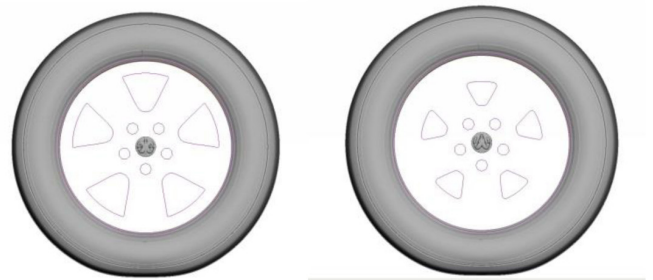


Figure 2. Wheel A- 5 spoke aluminum wheel on the left and Wheel B - 5 spoke aluminum wheel on the right with smaller openings.

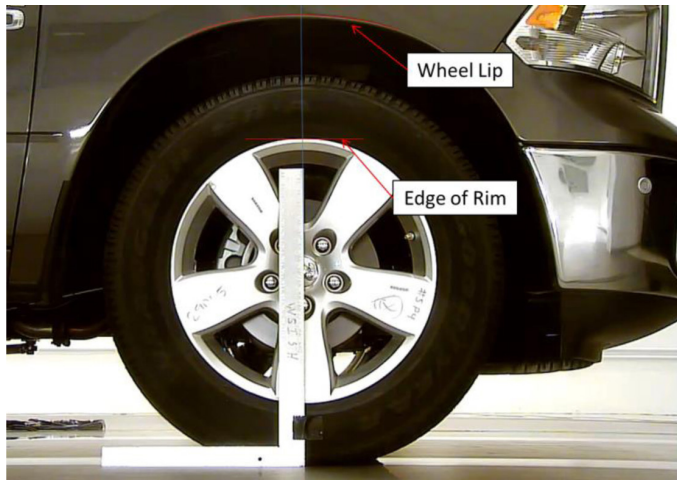


Figure 3. Wheel A- with tire at rest.

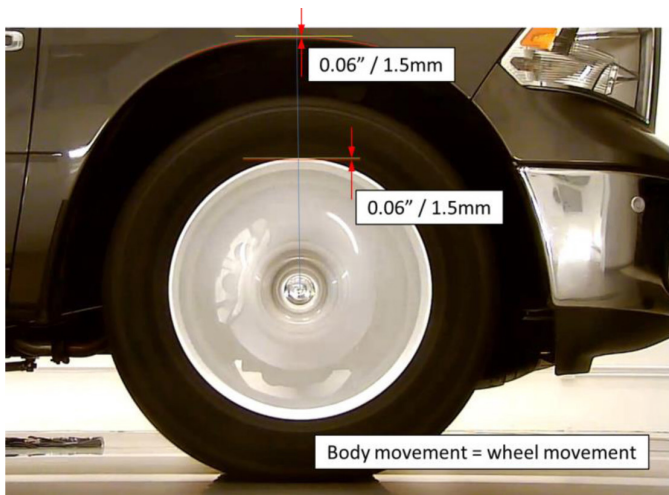


Figure 4. Wheel A- with tire at speed 31.3 m/s, showing a 1.5mm wheel lip rise.

THE INSTRUMENTATION

The instrumentation system by Aeroprobe used for this wind tunnel test was the exact same used in the minivan study [1]. This system included an Omniprobe capable of acquiring pressure and three dimensional velocity data for flows high amounts of swirl. The omniprobe features a micro-machined spherical tip with 12 pressure ports that allows measurement of ± 150 degrees of flow angles.

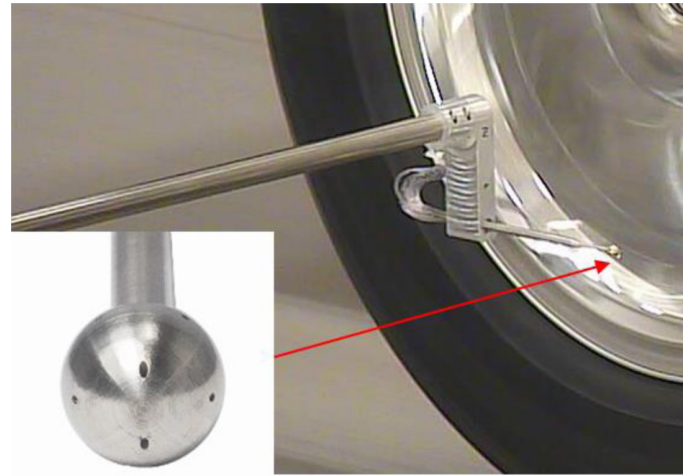


Figure 5. Omniprobe Geometry (image from aeroprobe.com)

The probe was mounted to a traverse system shown in figure 6 also supplied by Aeroprobe.

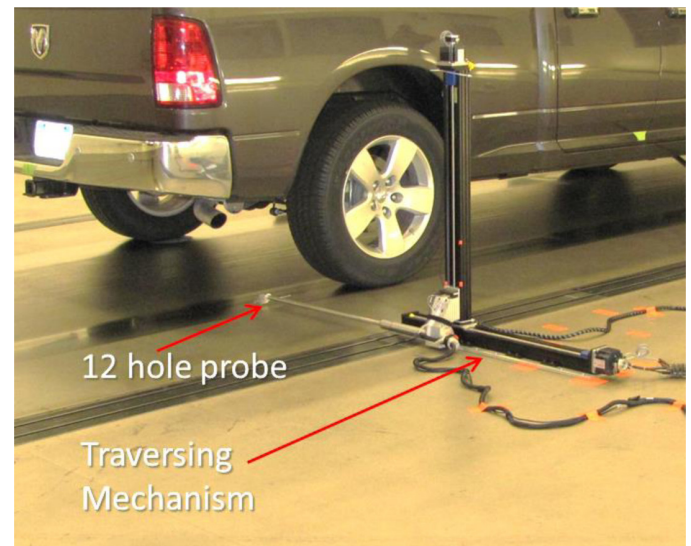


Figure 6. Traversing system at Windshear wind tunnel.

SAMPLING PLANES

Data from the 12 hole probe was collected on five sampling planes as illustrated in Figures 7 through 11. These were located to collect as much data as possible in the areas of the flow around the spinning wheels that are relevant for determining how well the CFD solution is replicating the critical flows. The data was collected after the flow was allowed to settle for 1 second and acquired at 386HZ for a duration of 4 seconds.

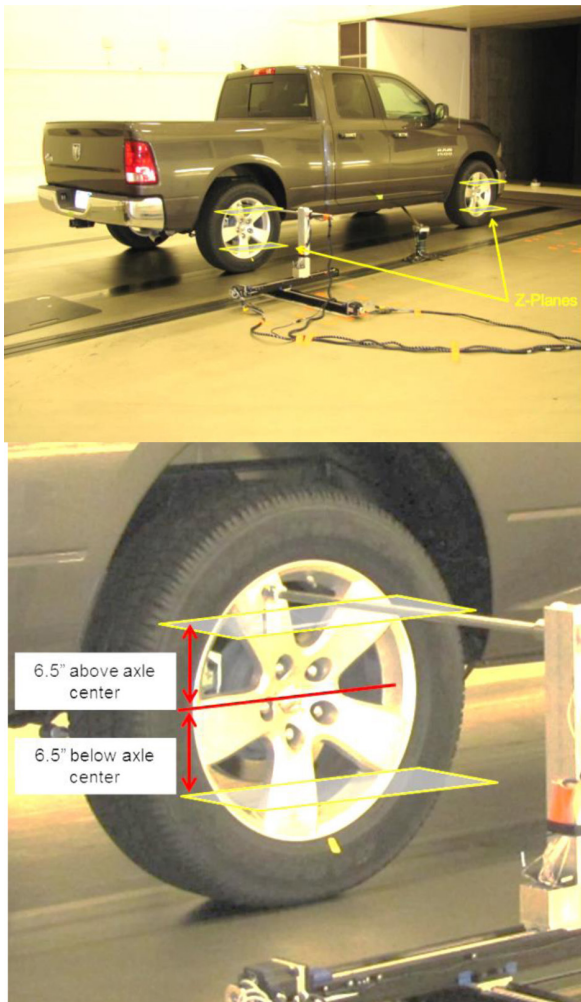


Figure 7. Two Z planes 6.5" above and below axle center line. Shown for front and rear tire on top, and detailed measurements on the bottom picture.

Z-Plane Datapoints

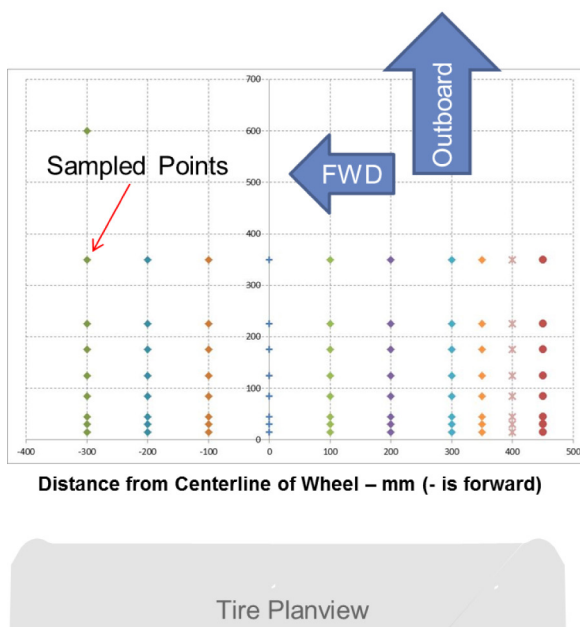


Figure 8. Data points for each Z-Plane

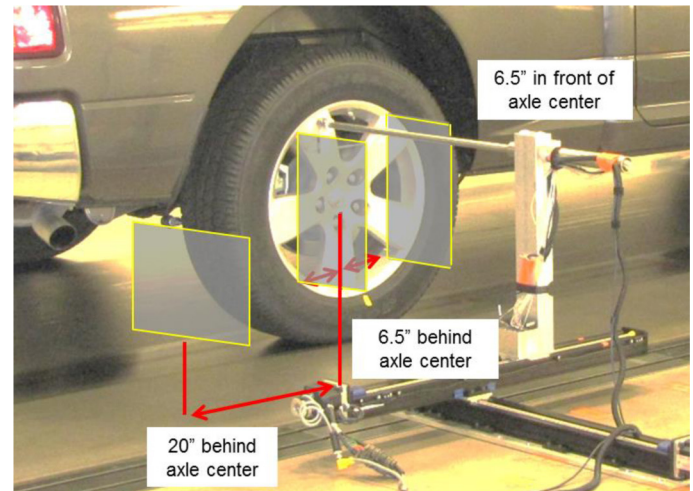


Figure 9. Three X planes outboard of tires.

X-Plane Datapoints

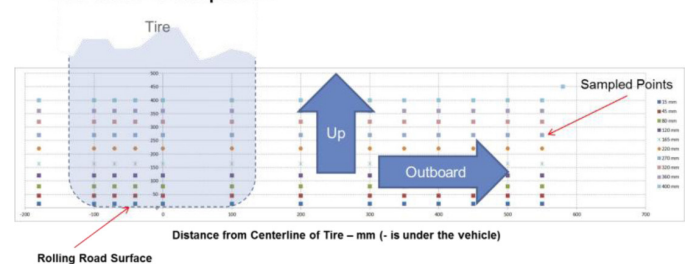


Figure 10. Data points for X-Plane behind the tire.

X-Plane Datapoints

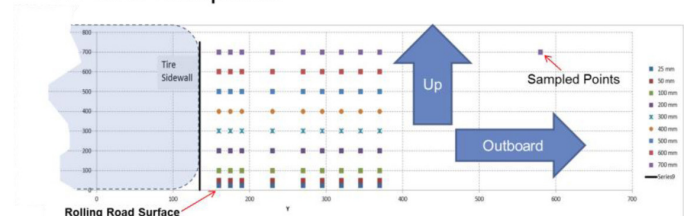


Figure 11. Data points for X-Plane on the side of the tire.

EXPERIMENTAL DATA

Aerodynamic forces and moments were collected at Windshear rolling road wind tunnel [7] as well as the flow field measurements near the front and rear tires using the 12 hole probe. Aspects like body lift at speed and tire growth was also documented.

Summary of Forces

Table 2 summarizes the drag and lift forces for two wheel configurations. The results include all the corrections applied for the wind tunnel measurements. Wheel B results in a slightly reduced drag compared to Wheel A, which is reasonable considering the smaller openings in Wheel B that allow smaller amount of airflow through the wheels. On the other hand, lift forces are increased, which is consistent with the rim configuration with a higher blockage that can increase the underbody pressure.

Table 2. Aerodynamic forces from experimental results.

Configuration	C_D	C_L	C_{LF}	C_{LR}
Wheel A: normalized by experimental Wheel A force coefficients	1.00	1.00	1.00	1.00
Wheel B – Wheel A	-0.001	+0.022	+0.012	+0.010

Velocity Measurement Planes

For the flow measurement of planar velocity field there are three cross-plane planes, i.e., x-aligned planes, and two horizontal planes, i.e., z-aligned planes. The former clearly presents the evolution of separated and vortical flow structures whereas the latter is also useful to understand flow changes in the streamwise direction, such as how much deflections in free stream occur and how the shear layers develop.

Front Wheel

X-Aligned Planes

As shown in Figure 12, the outboard wheel wake is characterized by the slight outboard and upward deflection of free stream and development of shear layers interacting with the impact of wheel rotation, which is noticeable at this location by the downward induced flow near the top of the rim height. In addition, the inflow or outflow through the rim openings affects the aforementioned rotating wheel flow. Compared to Wheel A, Wheel B shows less outflow especially for the lower half of the rim, which is closely related to the pushed-in lower shear layer and pushed-out higher shear layer.

Further downstream, as shown in Figure 13, the flow deflections develop into a counter-clockwise vortical structure near the ground. On the other hand, flow near the higher shear layer is subject to more complex interactions between wheel-arch and wheel-induced flows, and the measurement plane does not include the traces of other vortical structures. Wheel B exhibits a smaller profile of separated flow region near the wheel axle whereas the near-ground wake is larger than Wheel A. In addition the downflow and inflow components are stronger for Wheel B.

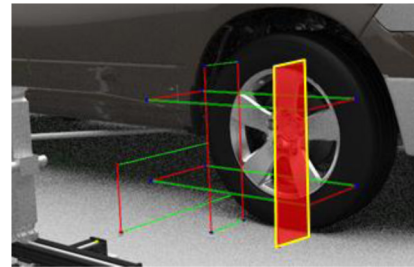
The stronger cross-plane flow for Wheel B is consistent with the more noticeable circulation near the ground for the further downstream wake region in Figure 14. Similarly the wheel wake structure is thicker for Wheel B at this location too.

Z-Aligned Planes

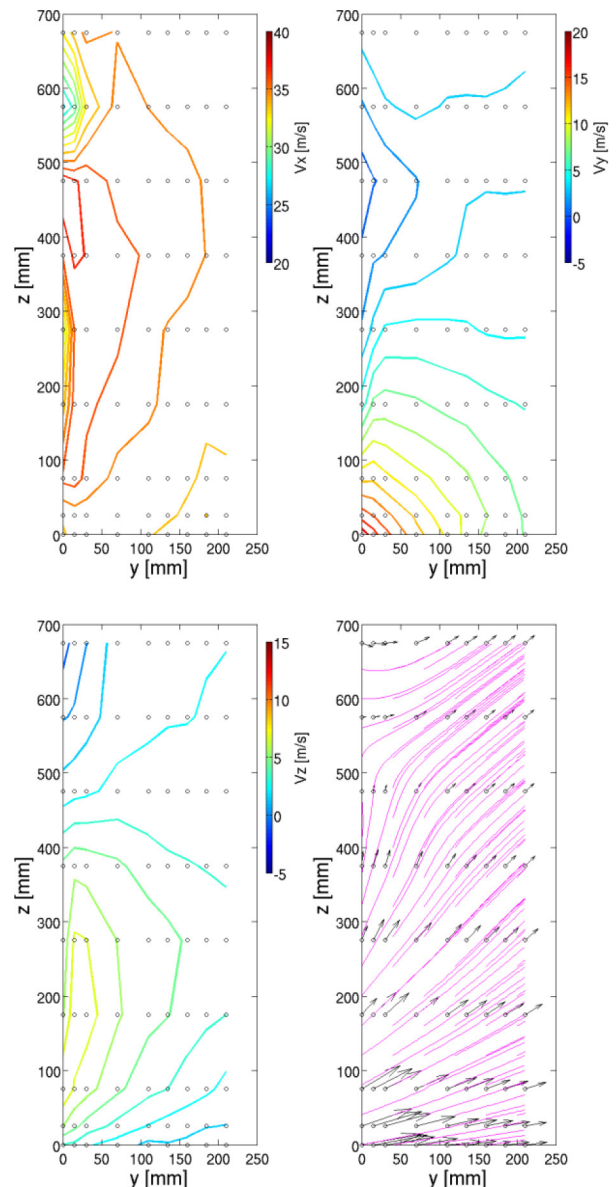
The two horizontal measurement planes are compared in Figure 15 and 16. The growing shear layers show the upper and lower portion of wheel wake, respectively. Being consistent with the cross-plane observations, Wheel B with the smaller rim openings generates more pushed-out higher wheel wake and pushed-in lower wheel wake.

Rear Wheel

For the rear wheel flow comparison only the results of the most downstream x-aligned plane are compared for brevity. Unlike the changes in the front wheel, Figure 17 shows Wheel A introduces higher magnitude of both outward underbody flow and inward outboard wheel flow, resulting in a stronger interactions between the two.



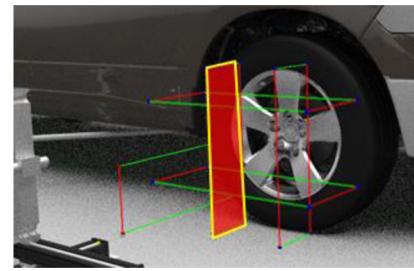
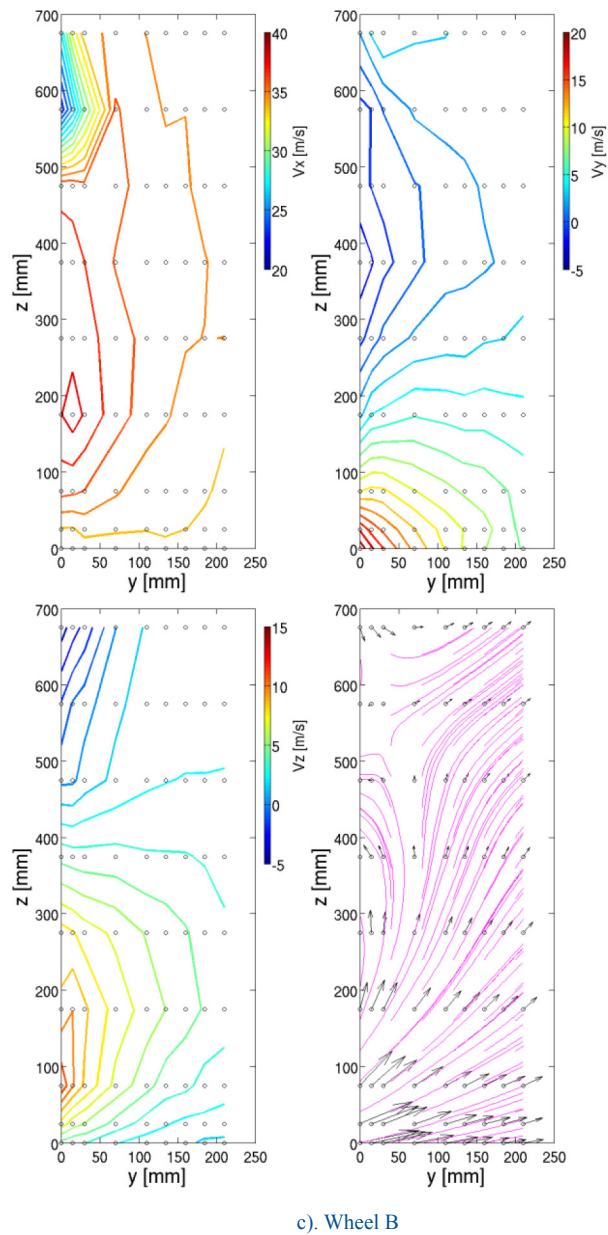
a). Measurement plane image



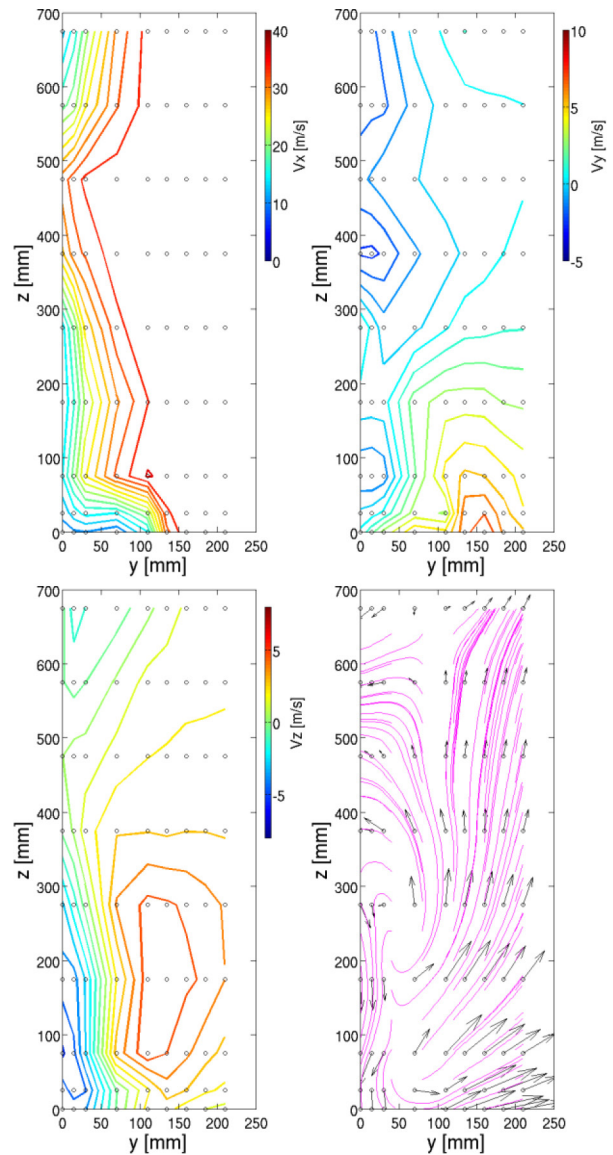
b). Wheel A

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Figure 12.



a). Measurement plane image



b). Wheel A

Figure 13.

Figure 12 (cont.). Experimental measurements for the x-aligned plane of $x = -165$ mm on the front wheel, showing x-, y-, and z-velocity components in m/s as well as planar velocity vectors and streamlines a) Measurement plane location b) Wheel A, c) Wheel B.