Characteristics of flow field past rotating wheels of cars, development of a method for analysis of flows

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New scientific results

<u>Thesis 1.:</u>
<u>Analysis of the flow field past isolated rotating wheel</u>

I have created a numerical model for the computation of the flow field past an isolated wheel rotating on a moving ground (Section 3.2). I have validated the numerical model via comparison of the results to those obtained from experiments published in the literature (Section 4.1). I have determined the characteristics of the flow field around both rounded- and sharp-shouldered isolated rotating wheels by means of both numerical simulation and wind tunnel experiments. Based on the results, I have completed the flow field model published in the literature with a vortex (denoted by **G** in the document), that exerts significant effect on the flow field and pressure distribution on the surface of the wheel. I have determined and explained the relationship between the structure of the flow field and the buildup and distribution of lift and drag on the wheel (Chapter 5.).

<u>Thesis 2.:</u>
<u>Analysis of the flow field around wheel rotating in a wheelhouse</u>

2.1 With simultaneous analysis and application of the streamlines, the distribution of the second invariant of the velocity gradient tensor Q detecting vortices of high dynamic impact on the flow, the total pressure distribution, the method of critical points and the wall streamlines I have improved the method of vortex skeletons for the analysis of complicated three-dimensional flows (Section 6.1).

2.2 I have created a numerical simulation model for the computation of the flow field past wheels rotating inside wheelhouse cavities (Section 3.2). I have validated the numerical simulation model via comparison of the results from numerical simulation with those obtained from experiments published in the literature (Section 4.2). With the aid of the numerical simulation model I have determined the characteristics of the flow field inside wheelhouse cavities and I utilized the method described in sub-thesis 2.1 for the determination of a more detailed flow field structure than that published before. I have concluded that in case of a wheelhouse of usual geometry there are 8 vortices influencing the flow field significantly (Sub-section 6.2.7). Out of these vortices I have extracted those of highest dynamical impact on their environment (Sub-section 6.2.6).

2.3 Via the determination of the flow field around four different, simplified vehicle model geometries, each of them representing the main characteristics of the flow around real road vehicles, I have corrected the statements made in the literature with the observation that the flow field inside the wheelhouse of the vehicle models is predominantly dependent on the geometry of the wheelhouse and on the distance between the front end of the body and the leading edge of the wheelhouse cavity, and, practically independent on the other geometrical parameters of the vehicle body, as well as on the Reynolds number within the usual range (Sub-section 6.2.6). I have determined the dependence of the structure of the flow field on the geometry of the wheelhouse cavity by means of parameter study (Sub-section 6.2.5).

<u>Thesis 3.:</u>

<u>Analysis of forces acting on the vehicle</u>

3.1 With the analysis of the flow field past a vehicle model representing the main features of the flow past real road vehicles, I have determined the distribution of forces acting on different surfaces of the vehicle model with and without presence of wheels and wheelhouses, and with and without side and lower opening covers on the wheelhouse, in more detail than can be found in the corresponding literature (Section 6.3).

3.2 I have concluded that 2/3rd of the increase in lift is due to the lift acting on the wheel, while the remaining 1/3rd of the increase is caused by the wheel-induced flow field modification past the vehicle body. The flow field inside the wheelhouse cavity does not affect the lift (Section 6.3).

3.3 I have concluded that, in case of the investigated representative vehicle model, the contribution of the wheel and the wheelhouse in the increase of the drag is $3/4^{th}$ of the total drag increase, while the remaining $1/4^{th}$ part of the drag increase is due to the wheel-induced flow field modification around the car body. The contribution of the wheel is $2/3^{rd}$, while the contribution of the wheelhouse is $1/3^{rd}$ in the ($3/4^{th}$ of the total) drag increase caused by the wheels and wheelhouses. The contribution of the wheel in the total drag increase on the vehicle model is approximately 50%, while the other 50% is due to the modification of the flow field past the vehicle model body caused by the effects of the wheel and the drag acting on the wheelhouse (Sub-section 6.3).

<u>Thesis 4.:</u>

<u>Analysis of unsteady flow fields</u>

4.1 In order to complete the statements published in the corresponding literature, I have determined the relationship between prescribed synthetic flow fields and the patterns of the corresponding POD modes (Section 7.4). In case of synthetic flow fields containing overlapping vortex positions, the first three POD modes contained the exact characteristics of vortices prescribed in the synthetic flow fields.

4.2 I have carried out PIV measurement of the flow over an open, rectangular cavity which represented a simplified model of a wheelhouse. (Section 8.). I have post-processed the measured results by POD to extract vortices of high kinetic energy. I have proposed the application of variables with which the real vortex structures can be detected and described. These variables are characterized by large values in vortices and small values in the free stream I have proven the appropriateness of the proposed procedure by means of conditional averaging (Sub-section 8.3.3).

4.3 During the analysis, I have concluded that, if vortices are to be detected by means of POD, then by the application of the proposal given in sub-thesis 4.2, using variables different from velocity, in case of real flows, POD modes characterized by high energy comparing to the others contain physical information (Sub-section 8.3.2). In the investigated cases, the previously mentioned conditions were satisfied by the first three POD modes, which is in good agreement with the experiences from the tests on synthetic flow fields, mentioned in sub-thesis 4.1 (Sub-section 8.3.2). I have concluded that certain characteristics of the flow and especially of vortices can be captured via the POD analysis of the instantaneous flow fields of an unsteady flow (Section 8.4).