Aerodynamic simulation of rotating wheels in a solar car

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1. Introduction

Every 2 years competitors from around the world set out on a grueling race across the Australian outback: the World Solar Challenge. The competing solar-powered cars are built by some of the brightest young minds on the planet. Student teams from all over the world push the limits of technological innovation by engineering and building a vehicle with their own hands, powered only by the sun. The competition is designed to promote research on solar-powered cars.

The Agoria solar team participates to the World Solar Challenge with the BluePoint: the result of years of research by different teams and thesis students from KU Leuven. To minimize the power consumption, an important objective is to reduce the drag. In the design phase the Agoria solar team ran many simulations to find the optimum design within the allowed limits of the competition. For an efficient mesh generation OMNIS™/HEXPRESS is used in this design process allowing to produce quick and easily high quality meshes for a large variety of design changes.

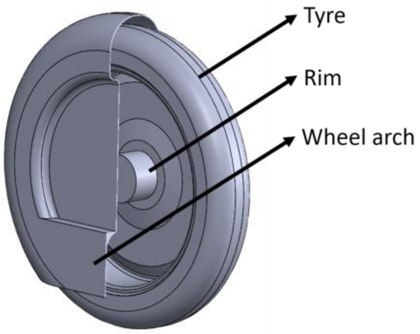
Where the wheels were often neglected in the aerodynamic simulations, the thesis of Kristof Borgions and Thomas Holemans [1] focusses exactly on this part of the car. In previous simulations the wheels were not taken into account or considered as static. In this research the influence of the rotation of the wheels is investigated.

The BluePoint of the Agoria solar team.

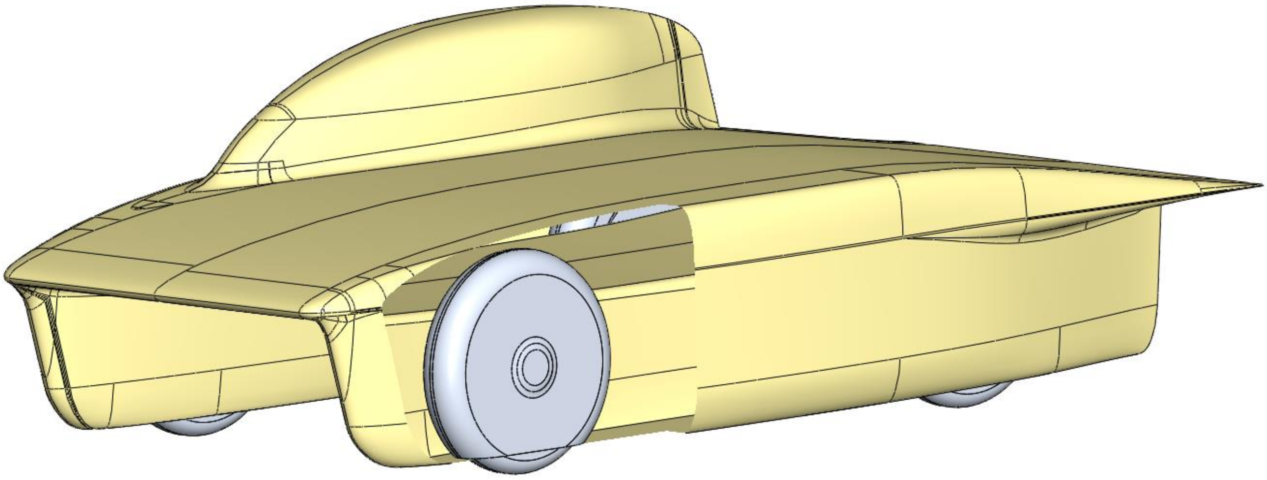
2. Project description

Simulations were performed on the solar car with rotating wheels and stationary wheels to be able to evaluate the impact of the rotation of the wheels on the total drag of the car. This is particularly interesting when comparing simulation results to real-life road conditions with rotating wheels and wind tunnel tests with stationary wheels.

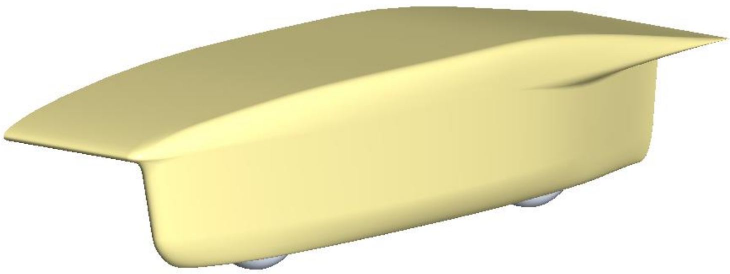
As a starting point previous simulations on the car without wheels were considered as performed by Vandervelpen and Uten [2]. To keep the computational time within reasonable limits, fitting to a master thesis work, the rim and the tire were simplified. For example the grooves in the tire were not taken into account. The wheel arch is also simplified. The gap for the suspension was closed as the flow inside the car is neglected. In addition, only half of the car is considered in the simulation, neglecting the flow around the canopy.



The simplified tire, rim and wheel arch.



Position of the wheel in the car.



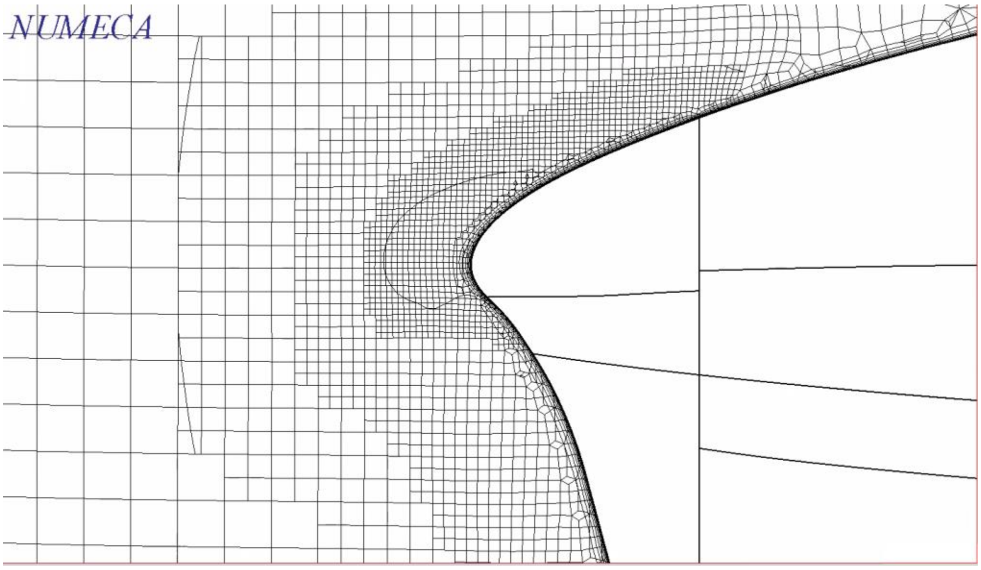
Half of the car as used in the simulations with a symmetry boundary condition.

3. Mesh generation

Starting from a CAD file in Parasolid format, a full hexahedral mesh is generated of around 11.5 Million cells. As the largest part of the drag comes from the boundary layer, the y+ varies around 1 allowing to compute the buffer layer within the boundary layer with sufficient detail.

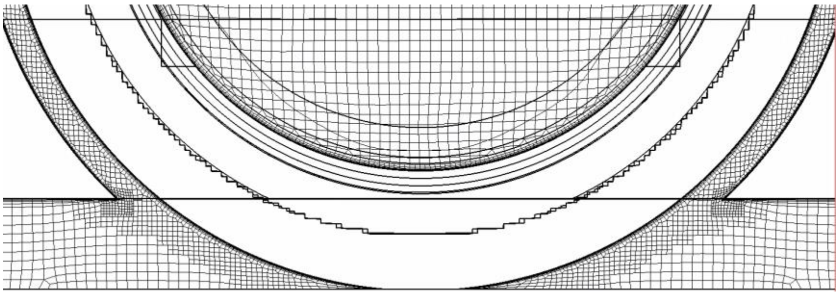
Where the original CAD contains many surfaces, OMNIS™/HEXPRESS allows to automatically group. An appropriate grouping eases the mesh set-up, the definition of the flow solver settings and the post processing.

Having the narrow fillet surfaces in a separate group allows, for example, to define additional refinements to capture accurately the curvature while keeping the cell count limited. The leading and trailing edge of the car can be captured accurately through an appropriate refinement as well.



Full hexahedral mesh at the leading edge of the car.

Seen the focus on the wheels in this work, particular care is taken to mesh this area. For example, the space between the wheel and the arch needs to be captured accurately. As the space between the wheel and the arch is variable, a proximity refinement is used. In this way the cell size is based on the distance between the two surfaces allowing to keep the cell count limited.



Full hexahedral mesh around the wheel.

The external boundaries are placed sufficiently far from the car to avoid any significant impact of the boundary conditions on the solution of interest (a domain of 25 times the length, 7 times the width and 5 times the height of the car).

In the post-processing the definition of separate groups in OMNIS™/HEXPRESS will allow to extract physical quantities for each of the groups separately to make a thorough analysis of the contribution of each of these components.

A mesh dependency study is performed with a coarser and two finer meshes to confirm mesh independency for the mesh of 11.5 Million cells.

4. Simulation set-up

For the simulations in the thesis the FINE™/Open solver was used for a 3D unsteady RANS simulation. Based on previous work [2] the k-ω SST turbulence model was used as this gave the best results compared to wind tunnel measurements.

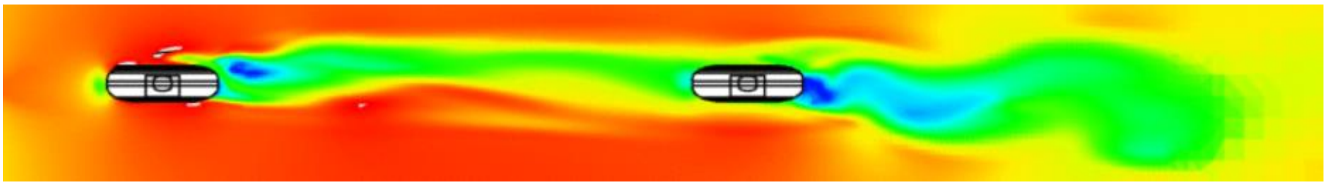
Apart from the freestream conditions at the inlet, the boundary conditions to use on the floor and the wheels are important. For the rotating wheels a Moving Wall boundary condition is used with an imposed radial velocity corresponding to the speed of the car. This is justified by the geometrical simplifications (no tire grooves or spoked rim) resulting in an axisymmetric shape of wheel. To be coherent with the rotating wheel, the floor has a translation equal to the velocity of the car. In reality stationary wheels (in a wind tunnel) would correspond to a stationary ground. However, in this research a moving floor is imposed also for the stationary wheels to be able to draw conclusions on the possible causes of differences between the rotating and stationary wheels.

Based on the evaluation of the Courant number a first estimation is made of the time step to use. After running a first simulation it is verified that a period of the unsteady phenomena is captured by at least 20 time steps. The used time step is 3.86×10^{-3} s.

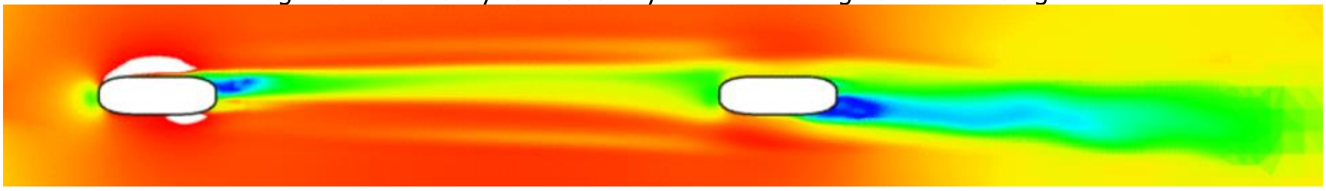
The second order central matrix scheme is used for its less dissipative character.

5. Results

The simulations were run on 26 cores with 160 Gb of RAM on a workstation of the 'Applied Fluid Mechanics and (Aero)Acoustics' research group of KU Leuven, campus Groep T Leuven. A first steady simulation was performed within 52 hours corresponding to 4.5 CPU.h/Mpoints. For the unsteady simulations there was a remarkable difference: where the simulation with stationary wheels take 440 hours to stabilize, the simulation with rotating wheels take only 44 hours. This difference can be entirely attributed to the vortex shedding that is observed in the case of stationary wheels. Due to the rotation of the wheels the amplitude and frequency of vortex shedding is significantly reduced.



Magnitude of velocity for stationary wheels showing vortex shedding.

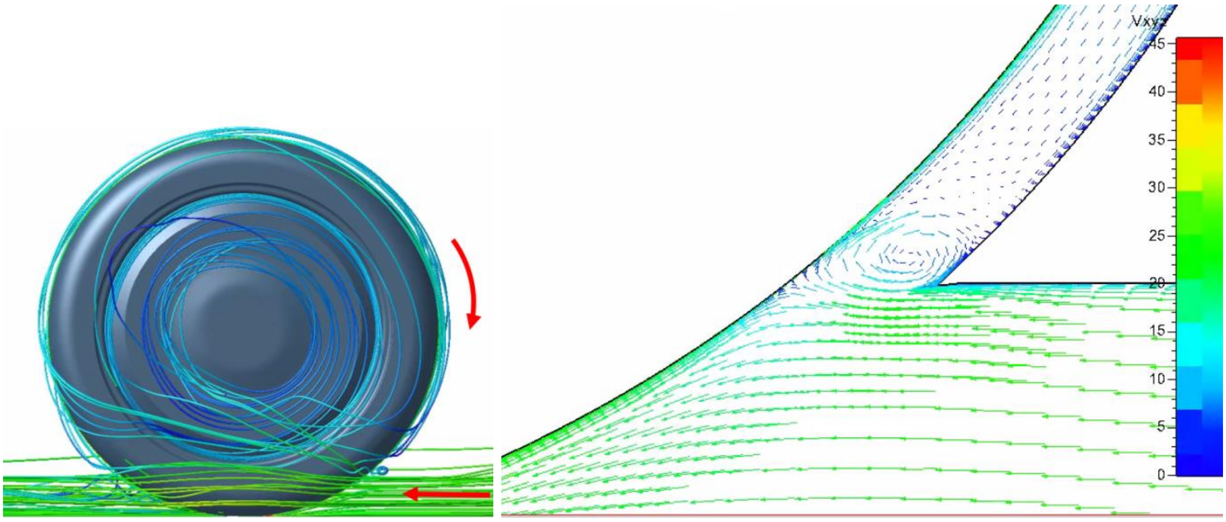


Magnitude of velocity for rotating wheels showing smaller vortex shedding.

A comparison of the skin friction drag shows only a small influence of the rotation of the wheels. The pressure drag on the contrary is largely influenced by the rotation of the wheels. In addition the simulations demonstrated that the front wheels have a higher pressure drag than the back wheels. This can be explained by the lower stagnation pressure for the back wheel as it is in the wake of the front wheel. Furthermore the flow is approaching the back wheel under an angle coming from the vortex shedding caused by the front wheel. The pressure field shows that the pressure in the wake just downstream of the front wheel (on the left) is lower than the pressure in the wake of the back wheel (on the right).

Pressure contour of stationary wheels

The simulations allow to get a more detailed insight in the flow field structures around the wheel caused by rotation. A small recirculation zone can be noticed at the front of the wheel and the wheel arch. Here the free stream flow from upstream of the car and the flow between the wheel and the wheel arch come together.



The computed C_dA compares within 0.95% with the one measured in a wind tunnel. As the present simulations did not include the canopy, the computed results were corrected based on previous results including the canopy [2].

6. Conclusions

This work with OMNIS™/HEXPRESS and FINE™/Open with OpenLabs™ is an example of a thorough work performed by students in the limited time available for a master thesis. It provides more insight into the flow structure around the rotating wheels and the significant impact on the pressure drag. This helps in particular to increase confidence in the comparison of simulation results with experimental results in road conditions and wind tunnels.

7. References

1. Borgions K., Holemans T., Aerodynamic simulation of rotating wheels in a solar car. KU Leuven, Faculty of Engineering Technology. Master thesis, 2019.
2. Vandervelpen E., Uten J., Testing of turbulence models for the aerodynamic simulations of a solar car, KU Leuven, Faculty of Engineering Technology. Master thesis, 2018.