

# MODELING OF THE HYDROPLANING PHENOMENON

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## INTRODUCTION

Hydroplaning is a unique phenomenon in which the water on a wet runway or highway is not displaced from the nominal tire-ground contact area by a rolling tire or by a moving but non-rotating (full-skidding) tire at a rate fast enough to allow the tire to make contact with the ground surface over its complete nominal footprint area, as would the case of operation on a dry surface. When hydroplaning occurs, the tire rides on a wedge or film of water over a part or all of its footprint area, depending on the conditions. This creates a situation where the vehicle experiences low (or near-zero) coefficient of friction and uplift forces in the fluid film capable to cause a loss of contact between the tire and the pavement. This causes a loss in braking ability and could lead to accidents.

Research in the NASA Langley Research Center involving bogie and nose-gear studies [1] led to the NASA hydroplaning equation shown in Equation (1), which is still being commonly used in the tire, aviation and automobile industries, and the highway and airport authorities.

$$v = 6.36\sqrt{p} \quad (1)$$

where the  $p$  is the tire inflation pressure in kPa and  $v_p$  is the hydroplaning speed in km/h. It has been shown by researchers that other than tire pressure, factors such as thickness of water, pavement surface texture, and tire tread design could affect the speed at which hydroplaning occurs [2].

Despite the advances in experimental studies, the development of a numerical model that can model the hydroplaning phenomenon is slow. This is primarily due to the complexity of the problem which involves the non-linear behavior of the pneumatic tire, the complex fluid flow and the non-homogeneous pavement surface characteristics. Models proposed by past researchers and existing software in the market today still could not offer solutions close to the experimentally obtained NASA hydroplaning equation. This article therefore describes an approach that makes use of computational fluid dynamics to describe the hydroplaning phenomenon and more specifically to model the NASA hydroplaning equation.

## NUMERICAL MODELING OF HYDROPLANING

### Concept of Hydroplaning Modeling

In a moving wheel frame of reference, the hydroplaning problem can be modeled as a layer of water and a pavement surface moving at a speed towards the wheel. A locked wheel is modeled as sliding on a flooded pavement surface. In this study, water is used as a contaminant and the temperature is assumed to be 20°C. Hydroplaning is assumed to occur when the average ground

hydrodynamic pressure is equivalent to the tire pressure of the wheel, i.e. the vehicle's load is equivalent to the hydrodynamic lift force.

## Geometry of Model

This proposed three-dimensional model has a geometry that is shown in Figure 1 which is derived from the tire deformation hydroplaning profile used by Browne [3] in his two-dimensional modeling of hydroplaning.

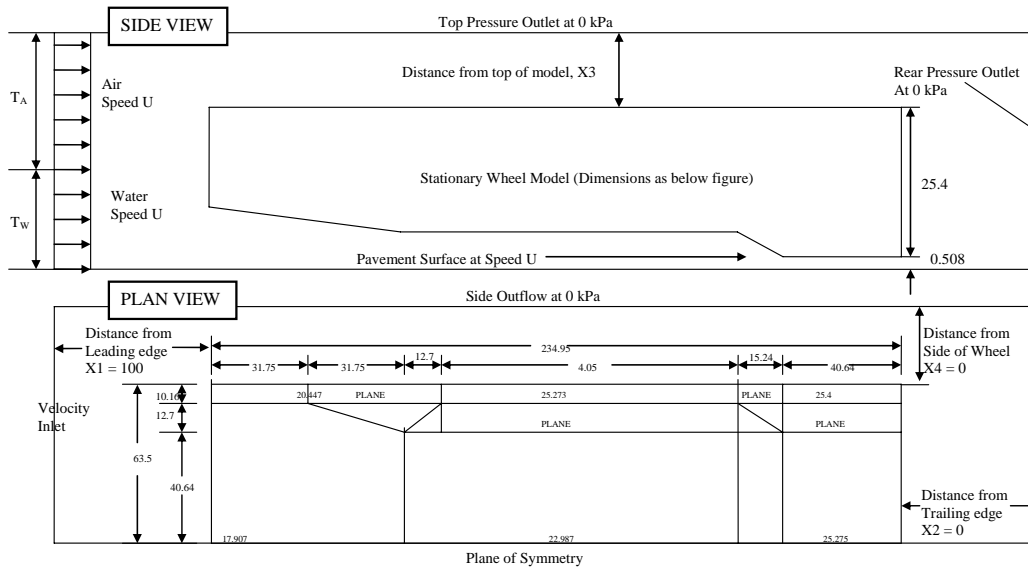


Figure 1. Geometry of the proposed three-dimensional model. (Dimensions are in mm.)

## Fluid Flow Model

The flow in hydroplaning is largely turbulent in nature and this has to be accounted for in the modeling of hydroplaning. It is therefore necessary to apply the semi-empirical standard  $k-\epsilon$  model for the turbulence modeling. The problem is solved numerically using the computational fluid dynamics (CFD) software FLUENT, using the finite-volume method.

## Pavement Surface Model

The pioneering experimental work of the hydroplaning phenomena done by Horne and Dreher [4] is performed on a glass surface. This article models the experimental setup of Horne and Joyner for verification purposes. In this study, a smooth plane pavement surface is assumed. The term “smooth” means that the average roughness height of the micro-texture is taken to be zero.

## Boundary Conditions Used

The upstream boundary conditions consist of a pair of inlets, namely a velocity inlet of 5.08 mm (0.2 in.) thick for water and a velocity inlet of 50.8 mm (2 in.) thick of air. A uniform velocity profile is used. The pavement surface is modeled as a moving smooth plane wall with no micro-texture. The speed of air, water and the pavement surface are kept as 55.3 km/h (34.4 mph) to be

consistent with Browne's experiment [4]. The inlet is placed at a distance of 100 mm away from the leading edge of the wheel. The trailing edge is modeled as a pressure outlet with the pressure set as 0 kPa (i.e. atmospheric pressure). The top boundary is set as a pressure outlet at the atmospheric pressure and the top boundary is placed at a distance of 25.4 mm (1 in.). The side edges are modeled as pressure outlets with the pressure set as 0 kPa (i.e. atmospheric pressure). It is noted that the centre-line of the wheel can be treated as a plane of symmetry. The locations of the boundaries have been chosen such that they would not have any significant effect on the ground hydrodynamic pressure under the wheel.

### **Material Properties**

The properties of water and air at 20°C are used in this study. The density, dynamic viscosity and kinematic viscosity of water at 20°C are 998.2 kg/m<sup>3</sup>, 1.002 x 10<sup>-3</sup> Ns/m<sup>3</sup> and 1.004 x 10<sup>-6</sup> m<sup>2</sup>/s respectively. The density, dynamic viscosity and kinematic viscosity of air at standard atmospheric pressure and 20°C are 1.204 kg/m<sup>3</sup>, 1.82 x 10<sup>-5</sup> Ns/m<sup>3</sup> and 1.51 x 10<sup>-5</sup> m<sup>2</sup>/s respectively.

### **Mesh Design of the Three-Dimensional Hydroplaning Model**

Using GAMBIT, the preprocessor of the CFD software FLUENT, the mesh for computation can be developed. Hexahedral and wedge elements are used to depict each finite volume. 10 8-nodes hexahedral elements are used for the smallest channel in the model. The optimal number of mesh elements needed to give a converged solution can be tested through a mesh sensitivity analysis. There are 394,900 mesh elements in the proposed model.

## **RESULTS AND ANALYSIS**

The ground hydrodynamic pressure profiles along selected lines in the wheel direction are shown in Figure 2. The average ground hydrodynamic pressure under the hydroplaning wheel is found to be 72.5 kPa. The recovery factor is found to be 0.620 which is close to NASA value of 0.644 with a percentage difference of 3.7%. This difference is acceptable, considering the fact that the NASA hydroplaning equation is empirically derived from a wide variety of tires operating in flooded pavements [1]. This means that the proposed three-dimensional model using a turbulent flow model assumption is an acceptable model in simulating hydroplaning.

The model is re-run using the plane of symmetry as the pavement surface model to verify the experimental results obtained by Browne [3]. It is noted that the experimental data points for the hydrodynamic pressure fit rather well to the ground hydrodynamic pressure profile obtained from the simulation as shown in Figure 3. The average ground hydrodynamic pressure is 67.0 kPa, yielding a recovery factor of 0.57. This corresponds extremely well with Browne's value of 0.56, showing the appropriateness of the model and the fundamental governing equations behind the hydroplaning theory.

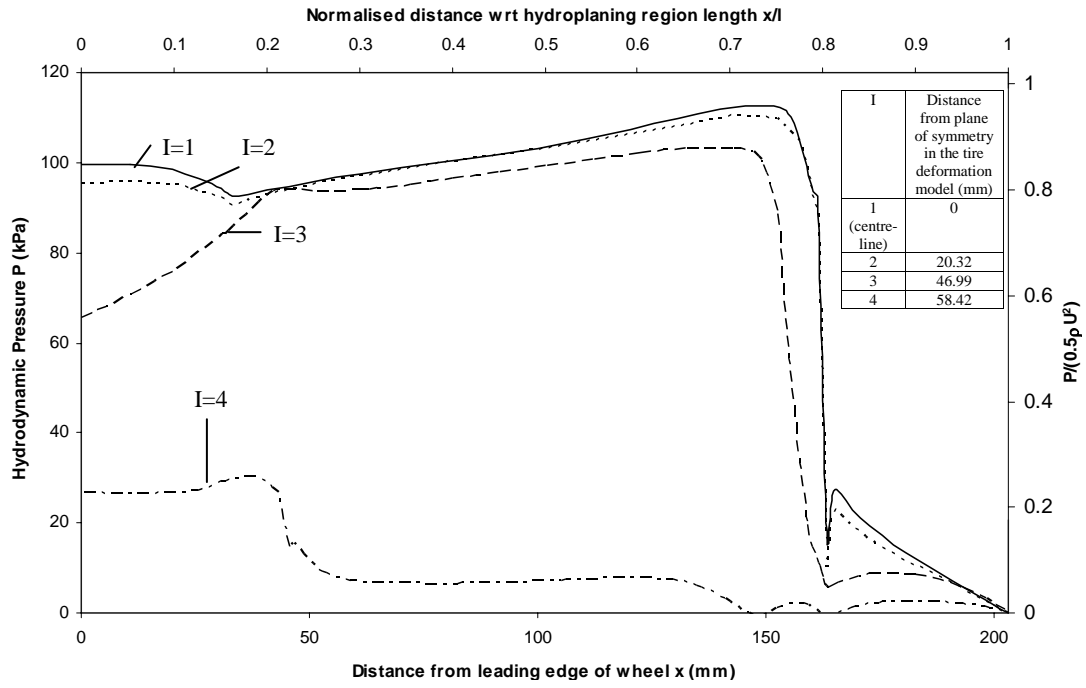


Figure 2. Ground hydrodynamic pressure distribution along lines under wheel

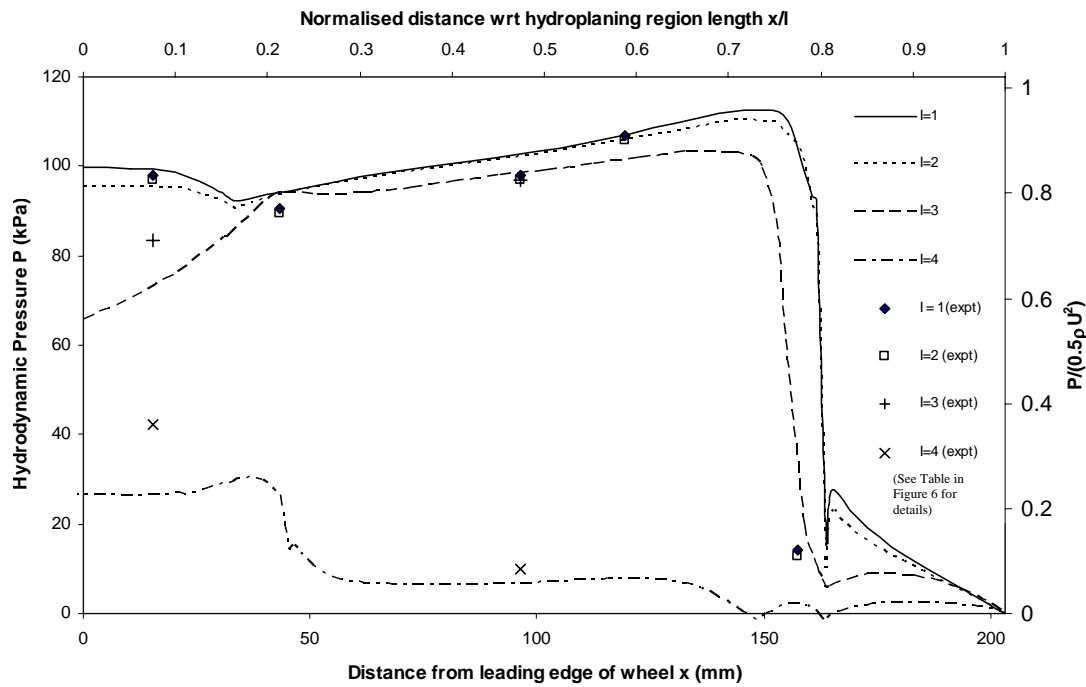


Figure 3. Comparison between the simulation using the 3D model with the plane of symmetry as pavement model and Browne's experimental results [3].

To derive the tire pressure-hydroplaning speed relationship and to compare it with the NASA hydroplaning equation, the velocities of the air, water and the pavement surface are varied. Speeds ranging from 0 km/h to 300 km/h are tested. Figure 4 shows the relationship between the tire pressure and the hydroplaning speed obtained from the simulations. It is seen that the model could accurately compute hydroplaning speeds predicted by the NASA equation. The computed results also match very well with the experimental results of the hydroplaning speeds obtained by Horne and Joyner [5] for different types of tires.

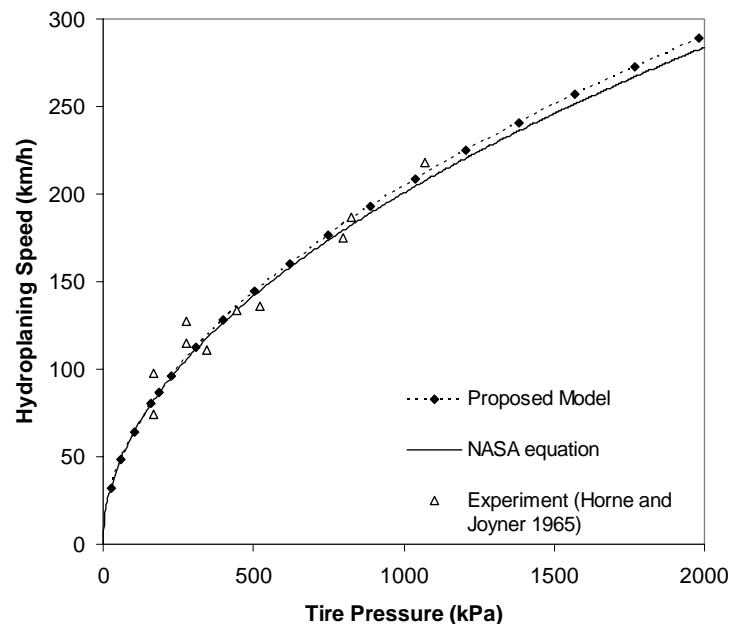


Figure 4: Comparison of simulation results with experimental data and NASA hydroplaning equation

## CONCLUSIONS

This article has described the model that makes use of computation fluid dynamics to describe the hydroplaning phenomenon. In order to model hydroplaning, this article has highlighted to need to consider the effects of the fluid flow characteristics, the tire deformation profile during hydroplaning and the pavement surface characteristics. It is shown that the model is able to provide ground hydrodynamic pressure distributions similar to that obtained in the experiments and is able to model the empirical NASA hydroplaning equation accurately. These indicates that such a model could be useful in aiding engineers and researchers understand the issues involved in hydroplaning and to develop different strategies to reduce the hydroplaning occurrences on highways and runways.

## REFERENCES

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