AN EVALUATION OF AERODYNAMICS PERFORMANCE OF A MOVING CAR WITH WIND TURBINE SYSTEM

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ABSTRACT

This study presents a simulation result of an evaluation of the aerodynamic performance of a moving car with a wind turbine system. Sedan type cars (approaching the size of Proton Wira car) were modeled using the SolidWork software and simulation was done by ANSYS FLUENT software. Three car models with different wind turbine system positions (in front of the front bumper, on top of the hood and on top of the roof) plus one model without the wind turbine system were simulated. The study proved that the position of the wind turbine system installation will change the characteristic of the air flow around the car body and affects the aerodynamic performance of the car. Extended front bumper of a car is not significantly affecting the aerodynamics performance of the car. This extended bumper seems to be the suitable area to install a wind turbine system and the investigation shows that the aerodynamics performance of the car improved due to the lower drag coefficient, $C_{d.}$ Optimum power generation will be based upon the amount of air velocity the duct system create in order to rotate the blades.

ABSTRAK

Kajian ini membentangkan hasil simulasi penilaian prestasia erodinamik kereta bergerak dengan system turbin angin. Jenis kereta Sedan (menghampiri saiz kereta Proton Wira) dimodelkan dengan menggunakan perisian SolidWork dan simulasi dengan menggunakan perisian ANSYS FLUENT. Tiga model kereta dengan kedudukan system turbin angin yang berbeza (dihadapan *bumper* depan , di atas hud dan di atas bumbung) dan satu model tanpa system turbin angin disimulasi. Kajian ini membuktikan bahawa kedudukan pemasangan system turbin angin akan mengubah cirri aliran udara di sekitar badan kereta dan member kesan kepada prestasi aerodinamik kereta. *Bumper* depan sebuah kereta yang direndahkan tidak member kesan ketara terhadap prestasi aerodinamik kereta tersebut. Malahan, bumper depan yang direndahkan tersebut dilihat menjadi kawasan yang sesuai untuk memasang system turbin angin dan kajian menunjukkan bahawa prestasi aerodinamik kereta itu lebih baik kerana *drag coefficient*,C_d yang lebih rendah. Penjanaan kuasa optimum oleh turbine angin akan bergantung bagaimana halaju udara yang lebih tinggi boleh diwujudkan didalam *duct system* untuk memutarkan turbin.

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LIST OF SYMBOLS

C_d	-	Drag Coefficient
C_l	-	Lift Coefficient
F_d	-	Drag Force
F_l	-	Lift Force
ρ	-	Air Density
v	-	Air Velocity
E	-	Turbine Efficiency
P	-	Power of Turbine

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Increasing use of gasoline-powered vehicles significantly contributes to environmental pollution, noise and depletion of crude oil reserves. Electric-powered vehicles are known to solve some of the problems associated with gasoline-powered vehicles, but such vehicles are not yet in widespread use [1].

There are three types of electric automobiles. The first one is called Electric Vehicle that stores electricity of electric utilities in the car borne battery. The second one is Solar Vehicle that carries multiple solar energy generating units to generate electricity to be stored in the car borne battery to propel motor. The third type of electric automobile generates electricity by using fuel battery. However, it is not widely used because of its huge volume and high cost. Besides all the three above-mentioned types, there are also some electric automobiles using all three ways of generating electricity.

However, the criteria by which each country judges the performance of electric vehicles are based on customers' demand and mainly concern with top speed, accelerating ability and the distance upon one charging (so called endurance). Any method that can optimize the performance is considered as important technical breakthrough in the design of electric vehicle and will contribute greatly to its popularization [2].

Many inventions and researches have been done all around the world relating to this idea by trying to invent a more applicable wind turbine for power generating system in vehicles. At the same time, a lot of discussion and opinion were done and expressed regarding the idea. There are some key points that the author has highlighted in this research based on what other people, inventors and researchers had discussed.

The first point that concerns the author in this research is the area to attach or mount the wind turbine on the vehicle so that it is able to get the air flowing around the vehicle to turn the turbine blades and therefore gain some energy. Secondly, investigation is needed to determine how the attached wind turbine on the vehicle will affect the aerodynamic performance of the car and also the drag force. Last but not least, the most important point of all to be highlighted is whether this idea is practical and economical enough to be implemented or not.

In this project, the author will evaluate the aerodynamic performance of a car when a wind turbine is attached or mount on the front bumper of the car. This project involves the simulation of the car model with three different cases in which a car with its original bumper as shown in Figure 3.1, a car with front extended bumper as shown in Figure 3.2, and a car with front extended bumper and wind turbine attached as shown in Figure 3.3 to 3.5. Computer simulation software, ANSYS FLUENT will be used to simulate and investigate the effects of wind turbine against aerodynamic performance of the car. In addition, the study also covers the process of designing an optimum wind turbine system for harnessing wind energy in cars.

At the end of the study, a result that compare the aerodynamics performance of car with and without wind turbine system will be obtained and the optimum design of wind turbine system for harnessing wind energy in car will be proposed.

1.2 Problem Statements

Based on existing inventions and previous researches, forthis project, the author is interested on several issues regarding the idea of electrical vehicle with wind turbine system. The appropriate position for the installation of wind turbine system will reflect other factors that shouldalso beconsidered. Beside the appearence factor, the most interesting factor to be discussed is the drag force of the car. How far the wind turbine system effects the drag of the car will be investigated and explained in detail towards the end of this project. The author will alsoinvestigate the effect of extended front bumper on the aerodynamic performance of a car. The author will study the advantages of wind turbine installed in front of the carif exist.

1.3 Research Objectives

The purpose of the research is to accomplish four main objectives as follow;

1. To evaluate the aerodynamic performance effected by extended front bumper of a car.
2. To evaluate the aerodynamic performance of a car with and without wind turbine system.
3. To investigate the impact of wind turbine position on a car body.
4. To estimate power generation by wind turbine system for wind energy harnessing in car.

1.4 Research Scopes

As the research's boundaries, the author has set several limitations describes as follow;

1. Development of 3D model of the sedan type car by using Solidworks software.
2. Evaluation of aerodynamics of the car model by using ANSYS FLUENT software
3. Design and develop 3D model of the wind turbine system.
4. Evaluation of power generated by the proposed wind turbine system.

CHAPTER 2

LITERATURE REVIEW

2.1 Aerodynamic of Vehicle

The external flow is the flow over bodies that are immersed in a fluid, with emphasis on the resulting lift and drag forces. When a fluid moves over a solid body, it exerts pressure forces normal to the surface and shear forces parallel to the surface of the body. We are usually interested in the resultant of the pressure and shear forces acting on the body rather than the details of the distributions of these forces along the entire surface of the body. The component of the resultant pressure and shear forces that acts in the flow direction is called the drag force, and the component that acts normal to the flow direction is called the lift force [3].

Drag is usually an undesirable effect, like friction, and we do our best to minimize it. Reduction of drag is closely associate whit the reduction of fuel consumption in automobile, submarines, and aircraft; improved safety and durability of structures subjected to high winds; and reduction of noise and vibration.

The drag and lift forces depend on the density ρ of the fluid, the upstream velocity *V*, and the size, shape, and orientation of the body, among other things, and it is not practical to list forces for a variety of situations. Instead, it is more convenient to work with appropriate dimensionless number are the drag coefficient C_d, and the lift coefficient C_l, and they are defined as

Drag coefficient: $$C_d = \frac{F_d}{\frac{1}{2}\rho V^2 A} \qquad \text{……………………………….(1)}$$

Lift coefficient: $$C_l = \frac{F_l}{\frac{1}{2}\rho V^2 A} \qquad \text{……………………………….(2)}$$

Where A is ordinarily the frontal area which is the area projected on a car normal to the direction of flow of the body.

Car manufacturers try to attract consumers by pointing out the low drag coefficients of their cars. The drag coefficients of the vehicles range from about 1.0 for large semitrailers to 0.4 for minivans and 0.3 for passenger cars. In general, the more blunt the vehicle, the higher the drag coefficient. [3]

2.2 Electric Vehicle

An electric vehicle (EV), also referred to as an electric drive vehicle, uses one or more electric motors or traction motors for propulsion. Three main types of electric vehicles exist, those that are directly powered from an external power station, those that are powered by stored electricity originally from an external power source, and those that are powered by an on-board electrical generator, such as an internal combustion engine (hybrid electric vehicles) or a hydrogen fuel cell[4].

A hybrid electric vehicle (HEV) is a type of hybrid vehicle and electric vehicle which combines a conventional internal combustion engine (ICE)propulsion system with an electric propulsion system. The presence of the electric power train is intended to achieve either better fuel economy than a conventional vehicle or better performance. There are a variety of HEV types, and the degree to which they function as EVs varies as well. The most common form of HEV is the hybrid electric car, although hybrid electric trucks (pickups and tractors) and buses also exist. Modern HEVs make use of efficiency-improving technologies such as regenerative braking, which converts the vehicle's kinetic energy into electric energy to charge the battery, rather than wasting it as heat energy as conventional brakes do. Some varieties of HEVs use their internal combustion engine to generate electricity by spinning an electrical generator (this combination is known as a motor-generator), to either recharge their batteries or to directly power the electric drive motors [5].

A plug-in electric vehicle (PEV) is any motor vehicle with rechargeable battery packs that can be charged from the electric grid, and the electricity stored on board drives or contributes to drive the wheels for propulsion. Plug-in electric vehicles are also sometimes referred to as grid-enabled vehicles (GEV) and also as electrically chargeable vehicles [6].

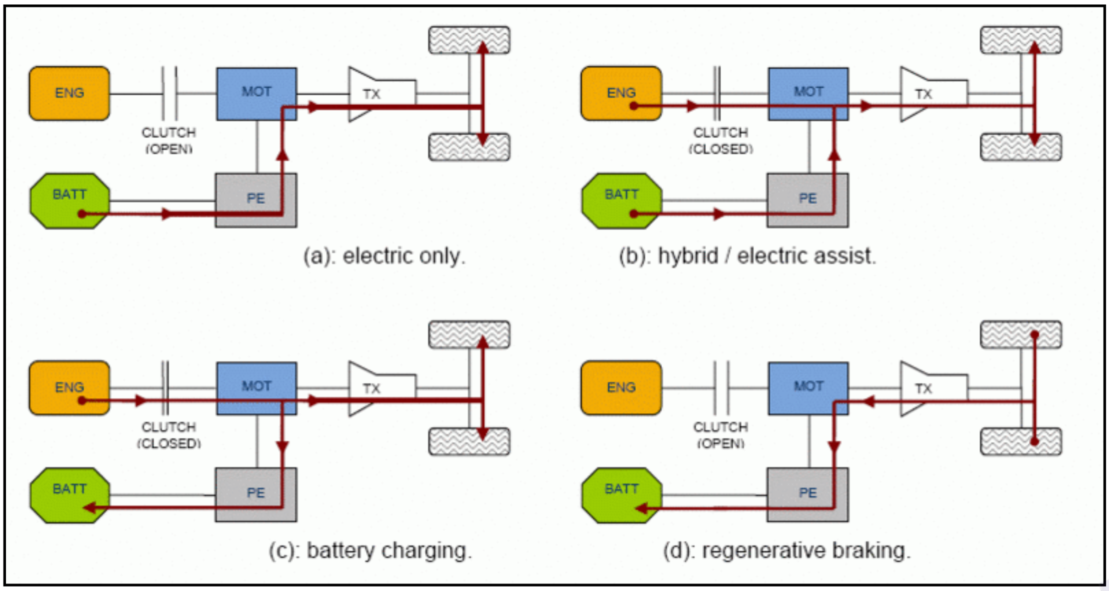


Figure 2.1: Principle of Hybrid Engine Operation [7].

A battery electric vehicle (BEV) uses chemical energy stored in rechargeable battery packs as its only source for propulsion. BEVs use electric motors and motor controllers instead of internal combustion engines (ICEs) for propulsion. A plug-in hybrid electric vehicle (PHEV or PHV), also known as a plug-in hybrid, is a hybrid electric vehicle with rechargeable batteries that can be restored to full charge by connecting a plug to an external electric power source[6].

2.3 Previous Invention of Electric vehicle with Wind Turbine

In 2003, Mitchell in his invention title “Current Powered Vehicle” came out with an invention to design a power system for powering a vehicle having an airflow or water flow channeling device mounted on the vehicle, a laterally mounted fan unit, and an electric alternator connected to the fan unit, in which airflow or water flow spins the laterally mounted fan thus generating electricity via the electric alternator to power the vehicle.

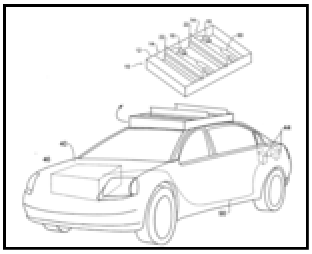


Figure 2.2:Design of Mitchell invention [8].

The objective of the invention is to design an air- or water-power system that can charge or maintain the charge on a vehicle battery and that can provide electricity to operate an electric motor for running a vehicle. The power system provides a means for electricity generation while the vehicle is in motion by using either or both of the naturally occurring air or water currents and/or the relative air or water currents generated by the vehicle when in motion. Broad-bladed horizontal fan blades laterally extending across the vehicle are used to catch the current and to transfer the current's energy to electrical alternators as shown in Figure 2.2. This electricity ultimately provides power to the vehicle as the electricity is provided directly to the electric motor that powers the vehicle, or is provided to charge the batteries, which are connected to the motor that powers the vehicle.

Mitchell stated that, advantage of his design is that it provides for a more aerodynamic and hydrodynamic shape to the power system and as such is able to lower the added drag force of the power system on the vehicle [8].

In 2006, Deets in his invention title “Wind Driven Generator for Powered Vehicles” came out with the invention quite similar to what Mitchell has done. The invention provides for a wind-powered battery charging system for an electrically-powered vehicle, a vehicle utilizing that system, and a method for charging a vehicle battery using air or wind power.

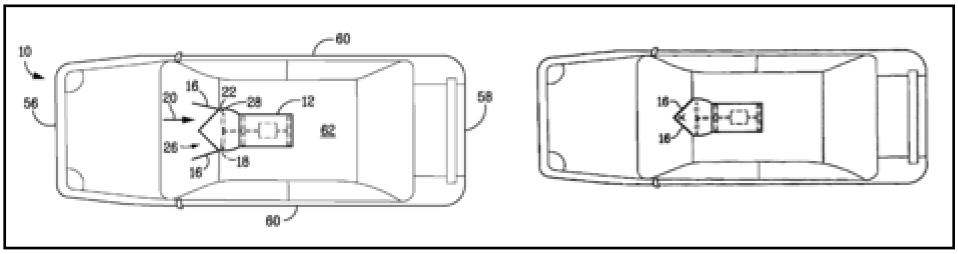


Figure 2.3: Design of Deets Invention [1].

In this invention shown in Figure 2.3 above, a shrouded enclosure is mounted to a vehicle roof, the shrouded enclosure comprising an air intake formed by controllable shrouds, a turbine, an electricity generating device, and a discharge outlet. The turbine is interposed between the air intake and the discharge outlet, operatively connected to the electricity generating device and adapted to operate by the air passing through the shrouded enclosure when the vehicle is in motion.
The turbine rotates about a turbine shaft mounted on a pair of bearing towers. The rotational energy of the turbine shaft is transferred to the electricity generating device.

Deets stated that, the advantage of his invention is the ability to utilize the controllable shrouds to both enhance air intake when open and reduce aerodynamic drag when closed. Another advantage of the invention is the ability to increase turbine bearing life through closure of the shrouds, thereby reducing the amount of time the turbine turns [1].

Before Deets, Kousoulis in 2005 had come out with his invention title “Motor Vehicle with Wind Generator Device”. The invention relates to power vehicles having a supplemental power plant that includes rotatable blades moved by the wind speed of the power vehicle to generate power for supplying electrical functions through a generator to allow power consuming devices within the power vehicle to function [9].

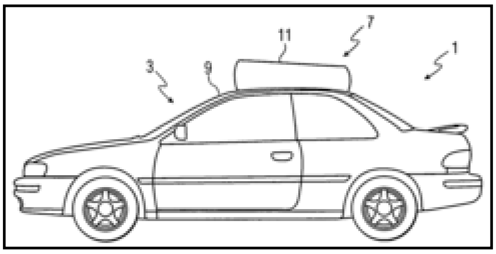


Figure 2.4: Design of Kousoulis Invention [9].

The general idea of the invention is to incorporate the wind turbine for production of electricity using the wind speed created by vehicles. The electricity generated can be connected to vehicle power accessories and to batteries so to charge them and eliminate the drainage on a main vehicle battery [9].

For this invention, Kousoulis stated that the placement of the supplemental power plant is not significant. The supplemental power plant may be located on any part of a vehicle, including a roof, a side, a front, a rear, and underneath the vehicle.

Besides the three inventions discussed earlier, there are several other inventions that are also interested on the idea of electrical vehicle with wind turbine. Amiks, with his invention title “Wind-Powered Car” objects to provide a wind-powered car having unlimited range and useful top speed capability in average wind conditions, and requiring no sailing skill [10]. Friedmann in his invention title “ Wind-powered, Battery-energized electric vehicle ” also objects to provide an operable, electric vehicle whose battery powered electric motors are charged by energy developed from venturi effect enhanced wind-electric generators as shown in Figure 2.5 [11].

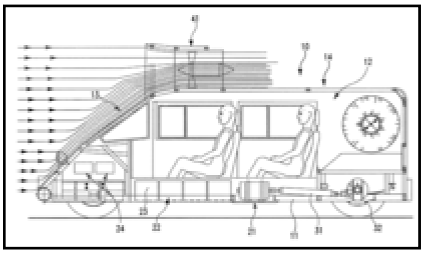


Figure 2.5:Design of Friedmann Invention [11]

All the previous inventions stated above are more toward to invent a system of wind turbine that is mounted on vehicle car which is only focus on the concept how the system can generate electric power by using wind turbine but not focusing on the detail system on electric generating, storing and power harnessing.

Hakala in his invention titled “System for Generating Electricity in Vehicle” came out with more focus approach where the main object is include a multi-stage impeller system, an improved means for increasing the velocity of the air entering the multi-stage impeller system and a method for an electric air compressor to initiate the impeller system when all other means fail to charge the battery. Another improvement that Hakala did in his invention are relates to an improved start-up/back-up air compressor and air duct [12].

Hakala stated in his invention, the response of an impeller blade depends upon factors such as the blade's shape and pitch and particularly the velocity of the air striking the blade. Wind striking the impeller blade rotates the impeller by imparting a portion of its kinetic energy. The impeller is attached to a generator of electric power which charges the battery. When the wind velocity decreases or increases, a flap valve of a bypass unit is operated in response to a sensor, the flap valve changing position thereby causing the wind to be redirected to the low-speed impeller or the high-speed impeller chamber, respectively. Thus, the low-speed or the high-speed impeller chambers will operate at maximum efficiency throughout the forward movement of a vehicle.

Besides that, the invention incorporates a start-up/back-up air compressor which discharges pressurized air to the top, rearward portion of the impeller so as not to obstruct the air flowing through the wind tunnel. Thus, by discharging pressurized air to rear of the impeller blade, the start-up/back-up air compressor has a direct impact on the system. Moreover, this mini-amp pressurized air compressor reduces excessive weight otherwise incurred with use of the air accumulator and also saves valuable space. Depending upon the specific design of the start-up/back-up air compressor, it may be connected to discharge air to the rear portion of the impellers of either the low-speed impellers or the high-speed impellers.

In term of the duct design, The Hakala invention improves upon the existing air ducts by incorporating a specially-shaped air scoop at the front portion of the air duct. This specially-shaped opening is simulative of a vortex, namely, rotating, small mass of controlled and regulated air in the form of a spiral configuring to a partial vacuum. In addition to narrowing axially in a rearward direction, the air scoop wall has an aerodynamic, funnel shape for spiraling the incoming air passing through the air scoop. The spiraling of the air further increases the velocity of the air passing into the venturi wind tunnels at the rear of the air duct.

An invention title “ Wind-powered Battery Charging System” by Pena relates generally to an electrically powered vehicle and more particularly to a system for charging batteries which utilizes a wind-operated turbine and generator for charging the batteries while the vehicle is in motion and a flywheel for charging the batteries when the vehicle slows down or is stopped [13].

2.4 Wind Turbine

A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy; a process known as wind power. If the mechanical energy is used to produce electricity, the device may be called a wind turbine or wind power plant. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. Similarly, it may be referred to as a wind charger when used for charging batteries [14].

Wind turbines are classified into two general types: horizontal axis and vertical axis as shown in Figure 2.6. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. There are a number of available designs for both and each type has certain advantages and disadvantages. However, compared with the horizontal axis type, very few vertical axis machines are available commercially.

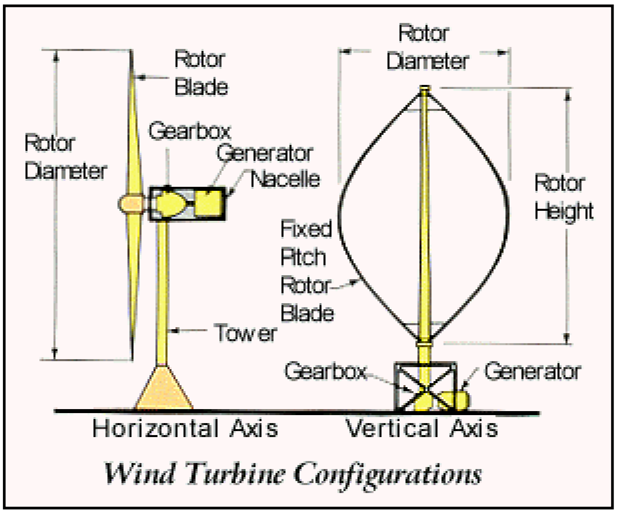


Figure 2.6: Types of Wind Turbine [15]

Horizontal-axis wind machines are more common because they use less material per unit of electricity produced. About 95 percent of all wind machines are horizontal-axis. A typical horizontal wind machine stands as tall as a 20-story building and has three blades that span 200 feet across. The largest wind machines in the world have blades longer than a football field. Wind machines stand tall and wide to capture more wind. Vertical-axis wind machines make up just five percent of the wind machines used today.

The typical vertical wind machine stands 100 feet tall and 50 feet wide. Each wind machine has its advantages and disadvantages. Horizontal-axis machines need a way to keep the rotor facing the wind. This is done with a tail on small machines. On large turbines, either the rotor is located downwind of the tower to act like a weather vane, or a drive motor is used. Vertical-axis machines can accept wind from any direction [15].

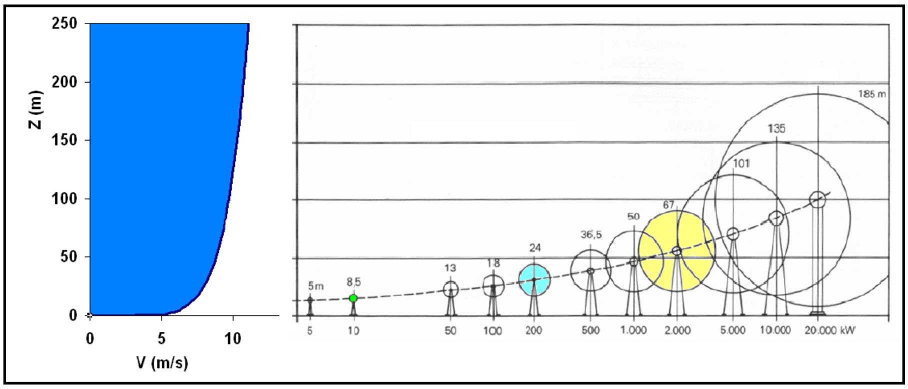


Figure 2.7: Typical vertical mean wind velocity distribution in the low atmospherical boundary layer, compared with the rotor size evolution [16].

Based on the Figure 2.7above, the power that a wind turbine can generate is dependent on the size of its rotor. From the graph, the author can conclude that, a larger turbine will generate or produce more power.

Savonius type rotor blade is one of the vertical axis wind turbines (VAWT). Savonius type rotor blade is a simple wind turbine that operates based on drag concept. The working principle of Savonius rotor resembles a cup anemometer. The low efficiency of VAWT limits its usage in large power production.

However, VAWT has several advantages over HAWT so much so that it is widely usedin another sector such as water pumping system. The most apparent advantage of VAWT is that it can operate in all wind directions and thus are built without using any yaw mechanism [17]. Other advantages include low noise and simplicity. Figure 2.8 shows the design of the Savonius type rotor blades.

Wind power is measured in many different units, such as horsepower, watts, and so on, depending on its application. The power extracted from the wind is not affected by changes in the air density except for extremely climatic locations and at high altitudes. The estimated power is also highly affected by velocity. Wind speed in the power formula is a cubic function, thus doubling the velocity increases the power eight times.

The basic wind-power equation is that used for estimating extractable power from any moving fluid mass [18];

$$P = \frac{1}{2}\rho A v^3 E \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

Where, P=power, ρ=the air density, A= swept area, V=velocity, E=total efficiency.

The equation provides all the parameters necessary to calculate the estimated power output of the system with the exception of the variable E, the total efficiency of the system. There are a number of considerations when calculating the overall efficiency of the wind turbine (E). These are efficiency of the rotor (Er), generator efficiency (Eg), and transmission efficiency (Et)[18].According to the Betz limit, as supported by Musgrove [19] there is at most only 59.3 % of the wind power can be converted into useful power. Some of the energy may lose in gearbox, bearings, generator, transmission and others [20].

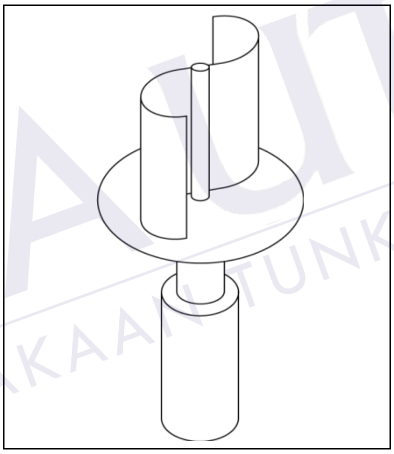


Figure 2.8: Savonius type rotor blade

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter includes a review of the research method and the appropriate design used for this study. As stated earlier, one of the objectives of this research is to evaluate an aerodynamic performance of a car to implement the idea for wind turbine system installation for energy harnessing. The method used in this study is the Computational Fluid Dynamics (CFD) analysis. Probably, these will involve several other computer software to design the model and simulation work. The data gathered from the simulation will be interpreted and discussed. The challenge on this study is to create the appropriate model to be used and to ensure the correct procedures during simulation work in order to get a precise result.

3.2 Aerodynamics Performance

The first process involved in this study is to design a car model to be used in the simulation. Solidwork 2012 software is the instrument used to accomplish this work. In this study, the author had divided the simulation process to two different cases which are based on different objects. The first case is meant to accomplish the objective of the study where the author wants to evaluate the aerodynamic performance effect by the extended front bumper of a car at the same time to investigate the impact of the wind turbine mounted on that position. Two different models were designed in order to do this investigation as shown in Figure 3.1 and 3.2 below.

The size of the car model is 4.2 m long, 1.7 m width and 1.8 m in height (approaching the size of Proton Wira car) with two different bumper height as shown in the Figure 8 & 9 below. These two models will be simulated with the CFD software (ANSYS FLUENT) to determine their drag coefficient C_d.

Simulation will be run in different parameters where the inlet velocity used are 36.11 m/s, 33.33 m/s, 30.56 m/s, 27.78 m/s, 25.00 m/s 22.22 m/s, 19.44 m/s and 16.67 m/s. Size of the boundary used for all simulation is 15 x 15 meter square for inlet and outlet area with 30 m length.

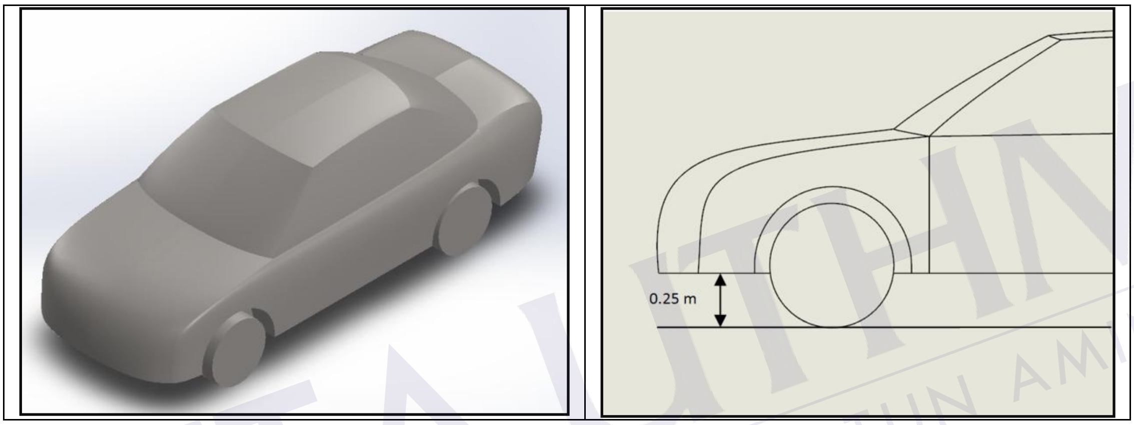


Figure 3.1: Car model with 0.25 m bumper height.

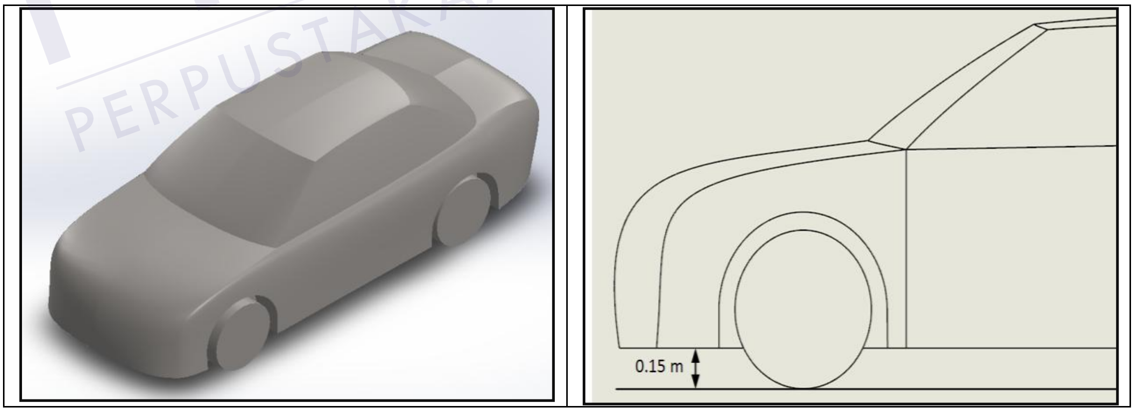


Figure 3.2: Car model with 0.15 m bumper height.

The second case is intended to explain the objective where the author wants to investigate the impact of wind turbine position on a car body. Three different models were created to achieve this where the wind turbine is positioned at the front of the bumper, on top of the car hood and car roof as shown in Figure 3.3 to 3.5 below.

The size of the car models are similar to the size used in the first case (4.2 m long, 1.7 m width and 1.8 m in height with the extended front bumper 0.15 m height from the floor). The front area for the wind turbine system is set to be 0.2 X 0.75 meter square for each model. In this case, the boundary size to be used is similar to the size used in the first case (15 m x 15 m square inlet and outlet area with 30 m length). All three models will be simulated under similar parameters where velocity inlet is 25 m/s (90 km/hr) to determine the drag coefficient C_d and lift coefficient C_l.

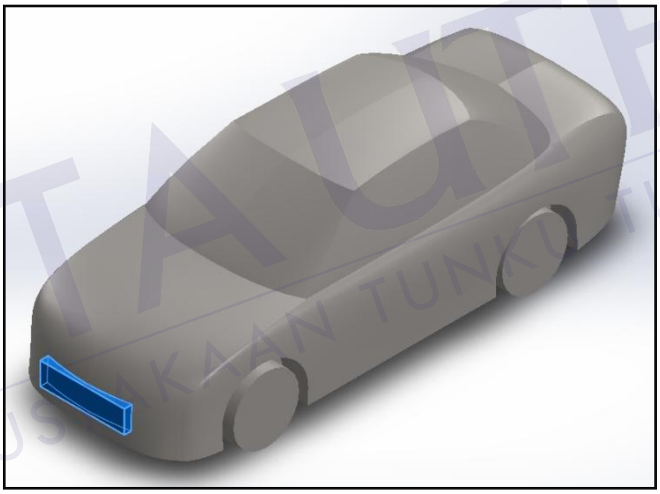


Figure 3.3: Car model with wind turbine mounted in front of the bumper.

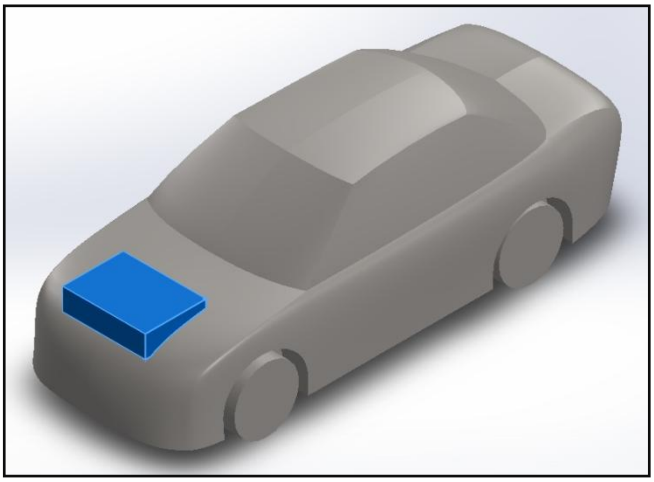


Figure 3.4: Car model with wind turbine mounted at the top of the hood.

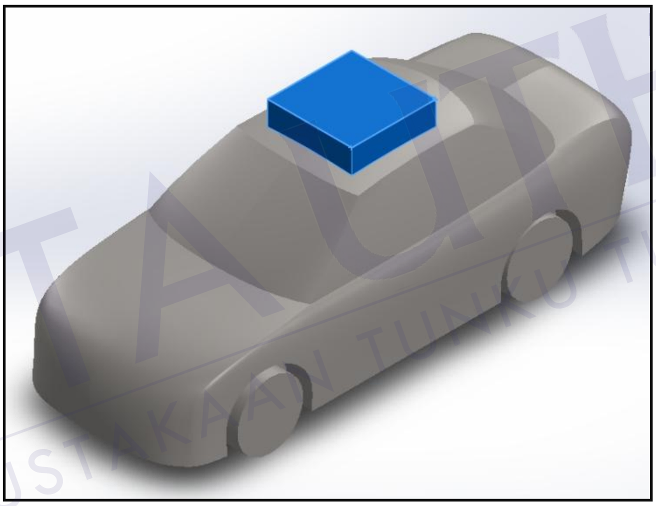


Figure 3.5: Car model with wind turbine mounted at the top of the roof.

3.3 Power Generation

To accomplish the last objective of this study, the author will try to design the appropriate wind turbine system to be installed on the car based on the result obtained from the earlier study. It was found that the suitable area to install the system is at the front of the car i.e. front bumper of the car.

From Figure 4.1, the result shows that the extended front bumper of the car will give the lower Drag Coefficient ,C_d compare of the non-extended front bumper, which means better aerodynamic performance for a car with lower bumper height. Based on Table 4.1 also, installing the system in front of the bumper will not affect the aerodynamics performance of the car significantly whereas it will affect if it was installed the at the top of the front hood and car roof due to high C_d value.

In this study, the Savonius Turbine model which is the vertical axis wind turbine (VAWT) type will be used. The whole body size of the system is set to be 0.1m in height and 1m width (0.1 m^2 front area). Different system will be designed by using Solidworks Software and simulated by using ANSYS FLUENT software to investigate the performance of the system itself.

Even though previous study proved that there is no significant change in the C_d value if the wind turbine system is installed at the front car bumper, the author wants to take the investigation further to study the aerodynamic performance of the car with a wind turbine system. A model of a car is designed with a duct system in front of the bumper with a Savonius type turbine inside is shown in Figure 3.6.

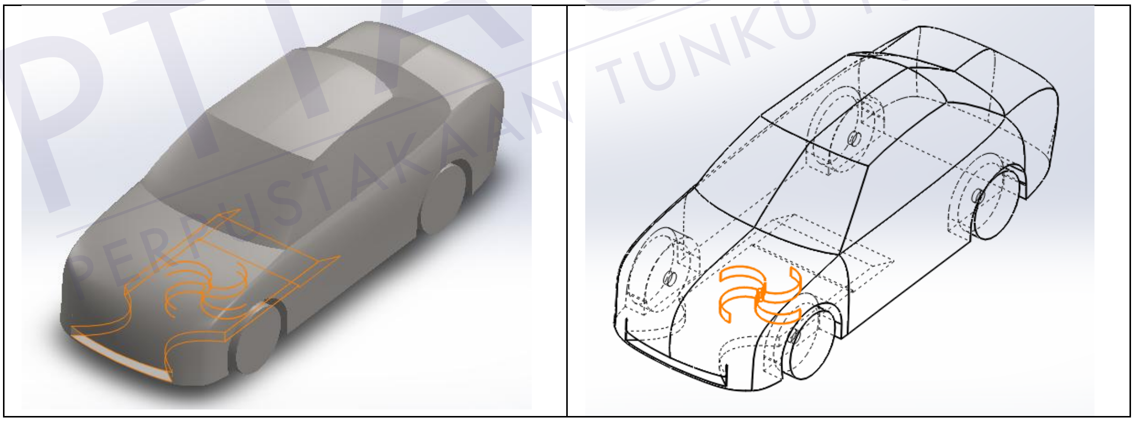


Figure 3.6: Car Model with duct system with wind turbine inside.

The model will be simulated by using the ANSYS FLUENT Software to obtain the C_d value to prove whether the idea of the system installation at that area will give a better result. Besides that, the purpose of this simulation is to identify the inlet air velocity that will enter the duct system so that the value can be used as the velocity-inlet value in the simulation of the ducting system which shall be done separately. For this simulation, the car is assumed to be travelling at 25m/s (90km/hr).

Figure 3.7 shows the basic design of the ducting system to be used in this study. The model will be simulated to identify the characteristic of the air flow inside the ducting. The speed of the air flow is the main parameter that will be used in the power calculation of the turbine that will be place in the ducting system.

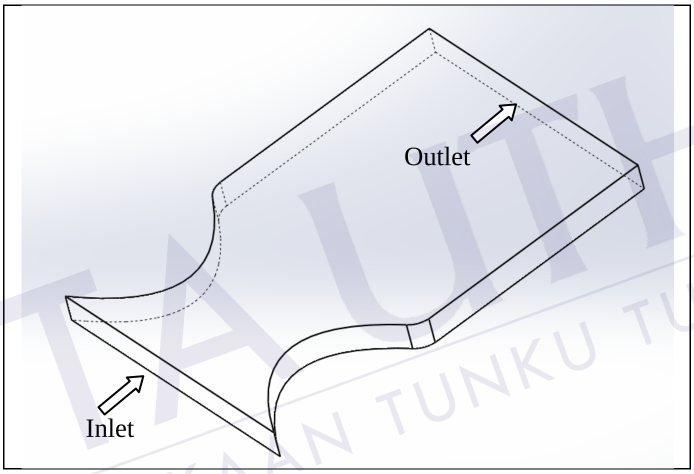


Figure 3.7: Ducting for Wind Turbine system

The value of estimate power generated by a turbine will be calculated by using the formula (3) as stated in the previous chapter;

$$P = \frac{1}{2}\rho A v^3 E$$

Where, P=power, ρ=the air density, A= swept area, V=velocity, E=total efficiency. The ideal efficiency of a wind turbine is known as Betz limit. According to the Betz limit, as supported by Musgrove [19] there is at most only 59.3 % of the wind power can be converted into useful power. Some of the energy may lose in gearbox, bearings, generator, transmission and others [20].

Figure 3.8 shows the two different duct systems with wind turbine that may give different result in order to identify the value of power can be generated. The size of the Savonius turbine is set to be 0.08 m height and 0.8 m width which has 0.064 m^2 of swept area.

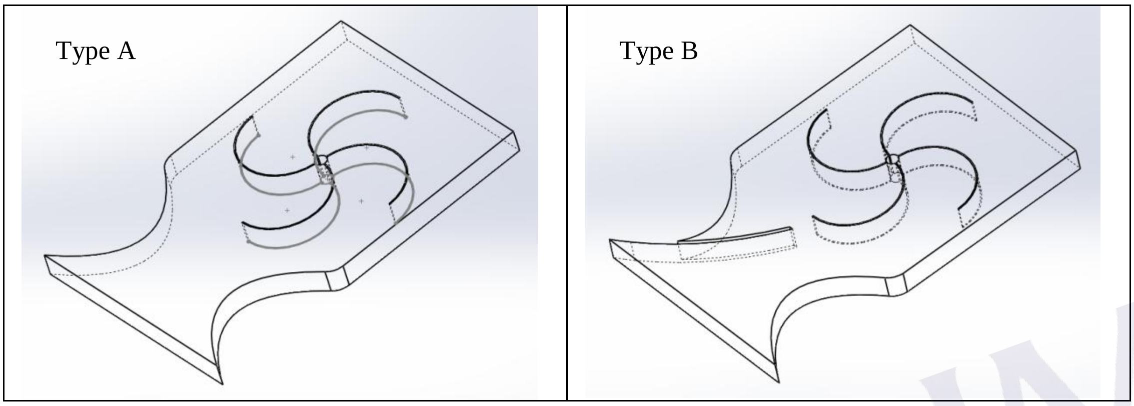


Figure 3.8: Duct System with Wind Turbine

3.4 Data Processing and Analysis

As stated earlier in this chapter, the model for both cases will be simulated by using CFD software in which the ANSYS FLUENT was selected by the author to investigate all interpreted information. The gathered data will be evaluated as a result for discussion. Result for each case will be discussed separately before a summary is done at the end of this report.

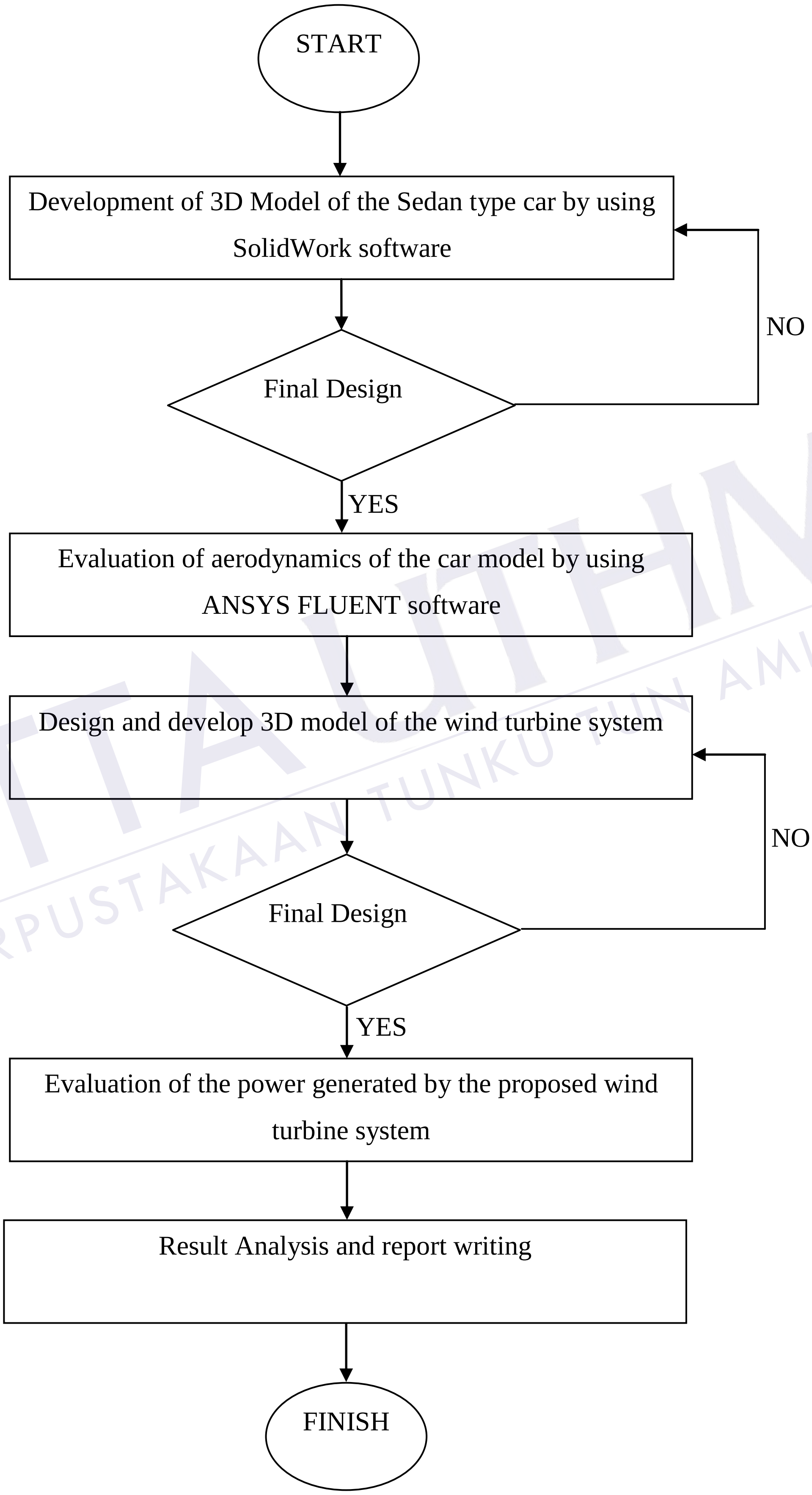
For the first case, the characteristic of the external flow around the two different models will be discussed. This includes the characteristic of the flow velocity, pressure cause of the flow toward the car body and most importantly the drag coefficient of the vehicle. Besides that, changes of the drag coefficient in different speed of the vehicle also will be investigated. Perhaps from the discussion of the first case, several questions will be answered and theories on aerodynamic of a car can be verified.

Among the questions the author wishes to answer prior to this investigation are “how much the speed of the car will affect the drag coefficient?”, “how much changes in drag coefficient effected by extended front bumper of a car?” and “if the changes is not greater enough, is the idea of installing something (wind turbine in this case) in front of the front bumper relevant?”.In order to find out these differences, the discussion will be based on figure gathered from the software used.

The purpose of the second case is quite similar to the first case where the author will investigate the characteristics of the external flow around the car body. The only difference in this case compared to the first case is that, the author wants to evaluate the aerodynamic performance of the car when the wind turbine system is mounted in different position of the car body as stated earlier in this chapter. Three different figures that show the flow around the car model body will be used in the evaluation.

The last study in this research is to evaluate the proposed wind turbine system, in which the findings of the simulation will be used to approximate how much power that can be generated from it.

3.5 Flow Chart of the Study Process



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