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Design and Analysis of Vortex Generator

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ABSTRACT

To save energy and to protect the global environment, fuel consumption reduction is primary concern of automotive development. In vehicle body development, reduction of drag is essential for improving fuel consumption and driving performance, and if an aerodynamically refined body is also aesthetically attractive, it will contribute much to increase the vehicle's appeal to potential customers. However, as the passenger car must have enough capacity to accommodate passengers and baggage in addition to minimum necessary space for its engine and other components, it is extremely difficult to realize an aerodynamically ideal body shape. The car is therefore obliged to have a body shape that is rather aerodynamically bluff, not an ideal streamline shape.

One way to overcome drag is to generate vortex flow at the rare end of the vehicle using vortex generators, reduction of drag in automobiles with vortex generators is already proved working in some previous studies, but no standard geometry is specified for the vortex generator. In this project we are going to compare the performance of different geometry's of vortex generators using Ansys 15.0 fluent workbench, all the 3d models of vortex generators are developed in Catia v5 software.

INTRODUCTION

A vortex generator (VG) is an aerodynamic device, consisting of a small vane usually attached to a lifting surface (or airfoil, such as an aircraft wing) or a rotor blade of a wind turbine. VGs may also be attached to some part of an aerodynamic vehicle such as an aircraft fuselage or a car. When the airfoil or the body is in motion relative to the air, the VG creates a vortex, which, by removing some part of the slow-moving boundary layer in contact with the airfoil surface, delays local flow separation and aerodynamic stalling, thereby improving the effectiveness of wings and control surfaces, such as flaps, elevators, ailerons, and rudders.

A Vortex Generator is considered as a passive flow control device which modifies the boundary layer fluid motion bringing momentum from the outer region into the inner region. Through this transfer of energy, the velocity of the inner region is increased at the same time as the boundary layer thickness is decreased, which in turn causes the separation of the flow is delayed. Furthermore, Lin et al showed the Drag reducing and the Lift increasing effect of sub boundary layer VGs.

Vortex Generators are applied on wind turbine blades with the major aim to delay or prevent the separation of the flow and to decrease roughness sensitivity of the blade. They are usually mounted in a span wise array on the suction side of the blade and have the advantage that they can be added as a post-production fix to blades that do not perform as expected. So, adding VGs is a simple solution to improving the performance of a rotor, Schubauer et al and Bragg et al.

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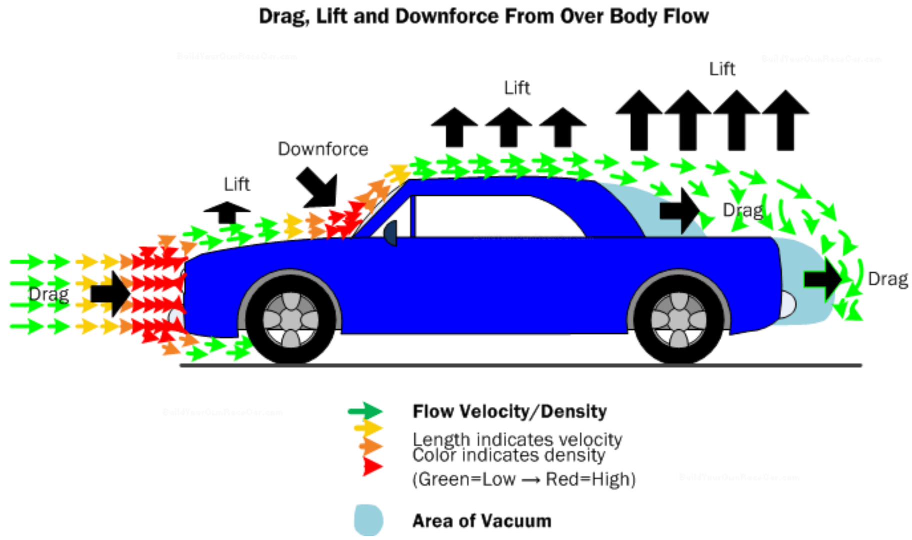


LITERATURE SURVEY

Vehicle power consumption reduction can be achieved by various means such as improved engine efficiency and aerodynamic drag reduction. From the early days, the designers recognized the importance of drag reduction and tried to streamline the design. Since the early 20-th century, large number of studies was carried out in this field and some are listed here [1-6]. This was also the time of formulating of basic principles of vehicle body optimization, and definition of drag lower limit. For a perfect car body configuration the lowest possible aerodynamic drag coefficient is ~0.16. Simulating road conditions has an effect on drag in the wind tunnel [4] and it is concluded that use of smooth immovable screen gives good result for comparative tests. The rear part of the vehicles make large contribution to the total drag and different forms of vehicle rear section has been studied [5]. In an interesting study [6], effect of variation in front and rear sections of minibus on total drag coefficient was presented. There is a good publication [3] evaluating different designs of vortex generators.

Aerodynamic drag of racing cars has probably received highest attention over last five decades in experimental and practical field of fluid dynamics. Many researchers and authors have described different forms of drag, possible reasons behind them and several ways of minimizing the drag. Katz's [7] work was fully devoted for the racing car aerodynamics and he described the different aspect of car design or streamlining starting from the first generation automobiles to most recent models, but no numerical or experimental procedure was explained to measure the drag. Computational analysis to reduce the drag is performed by Barbut et al. [8],Rouméas et al. [9] on road vehicle and by Guilmineau [10] on the simplified car body (Ahmed body). Islam and Mamun [11] performed numerical and experimental study to measure the aerodynamic drag, but their work was concentrated on sedan car only and they did not investigated any drag reduction technique. Aerodynamics of sedan cars and racing cars are different in many aspects like speed and effects of body constructions. Koikeet al. [12] introduced vortex generators to reduce the drag of racing cars. But effectiveness of vortex generator is restricted by the body shape of the car. Work of Krishnani [13] is not only very informative about the sport utility car, but also for drag reduction techniques. But this work does not concern with racing cars specifically. Adem [14] worked on vehicle aerodynamics and described the aspects of aerodynamic drag, but his work was subjected to a pick-up truck. Work of Damjanović et al. [15] is one of the recent studies on race car aerodynamic drag that includes both two dimensional and three dimensional analyses. But they only described the reduction of drag by using spoiler. Islam et al. [16] worked on calculating the drag force of racing car. A comparative drag analysis of sedan and square back car is performed by Bijlani et al. [17] and found that sedan car produces less drag than square-back car. A very few research paper has clear indication about the specific area that has to be used in drag calculation as different drag force is subjected to different area. In this work, numerical simulations are performed to analyses the drag of a racing car and some procedures to reduce it by reducing the flow separation.

The role of trapped vortices would be either to increase the base pressure, reduce the front stagnation pressure, or both. One way of reducing drag from the flow on the roof is to employ vortex generators (VGs) to keep the boundary layer attached. Combining vortex generators with suction and blowing at the rear of the car may reduce the size of the wake flow, decreasing the drag further. If the separated flow from the car's upper surface becomes trapped, the resulting low pressure region creates a net lifting effect similar to that on an aircraft wing; this is clearly undesirable. However, if the flow underneath the car could be actively trapped with suction, the induced low pressure zone produces a net downforce that would allow the car to have better road adhesion. Further, trapping the flow below the car stops it from being entrained into the wake, potentially increasing the back pressure and reducing flow unsteadiness. Generation of downforce with trapped vortices may, however, create some induced drag. Double fence concepts (18) could be used for vortex trapping underneath the car with wall suction for enhanced stabilization. The effects of the size and distance between the fences, suction distribution, and the clearance from the ground must be investigated to create stable vortices with minimum energy requirements. The sucked fluid could be used to break up the separated back flow, further shrinking the wake size. The energy to drive the suction pump could come from a small Stirling engine that operates on recovered waste heat. An alternative method is to mount a surface boundary with corrugations to trap multiple vortices; a similar concept was investigated by Yeung (19) on a wing with encouraging results. This latter solution may prove easier and cheaper to implement on a road car compared with a vortex cavity or fences that may be constrained for aesthetic reasons. However, underbody fences and discrete corrugations for vortex trapping are less intrusive.

Since the weight, centre of mass, tire condition, and propulsive power are strictly controlled for racing cars, aerodynamics has the highest potential in offering a competitive advantage in performance for such vehicles (20). In particular, downforce has a direct impact on road adhesion and cornering speeds necessary for winning races. But drag reduction and associated fuel savings can also be used by midfield teams to exploit the characteristics of some circuits.

Underbody diffusers are particularly efficient since they can contribute up to 50% of downforce without a significant penalty due to lift induced drag (21). The remaining downforce is mostly generated by the inverted front and rear wings. The inverted front wings with guide vanes act to suck air into the car's underbelly, creating a low pressure region and a downforce is generated. Just like on a lifting wing, the flow on the lower surface may become separated, leading to a reduction in downforce. To increase the ability of the inverted wing to generate greater downforce a leading edge flap to create a large vortex on the lower surface with wall suction for stabilization can be used.

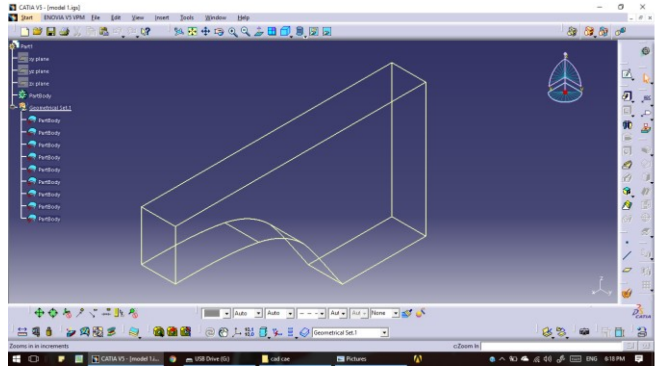
Alternatively, vortex cavities can be used for flow trapping. Using central bodies inside the cavities could stabilize the vortex without active suction; such systems were reportedly successful on the EKIP aircraft (22).

One particular study that looked into the impact of trapped vortices in race car ground effects was that of Garcia and Katz (11). They used a flat plate with vortex generators and a moving ground. The VGs generated vortices which were then trapped between the plate and the ground. The result was an increase in the downforce especially at low clearance heights from the ground and at various orientations of the VGs, even when the plate was mounted parallel to the ground. The results were later supported by Katz and Morey (23) who demonstrated that vortices generated by VGs create a suction force between the vehicle and the ground that improved the tire adhesion as well as the vehicle's cornering and traction performance.

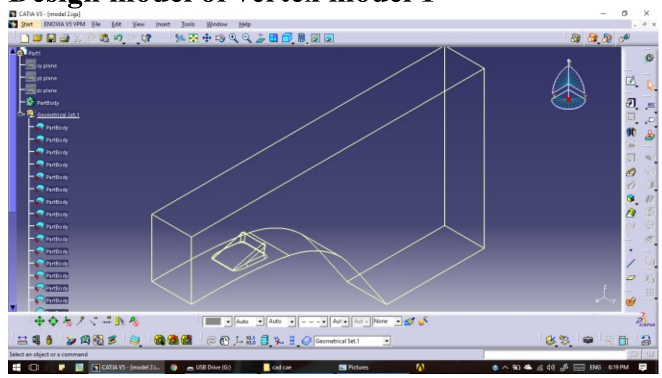
MODELING

There are various types of drawings required in the different fields of engineering and science. In earlier days, various drawing instruments like drafting machine, T-square, scale etc., are used to prepare drawings easily and accurately. But to obtain better ease in modifying the design and making calculations, the process of preparing a drawing is made in the computer using certain softwares. This use of computer systems is termed as computer aided design. It replaces manual drawing with an automated process.

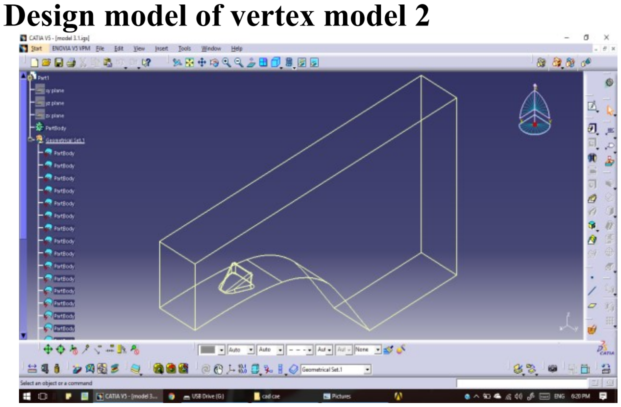
Design model view without vertex



Design model of vertex model 1



Design model of vertex model 2



Design model of vertex model 3

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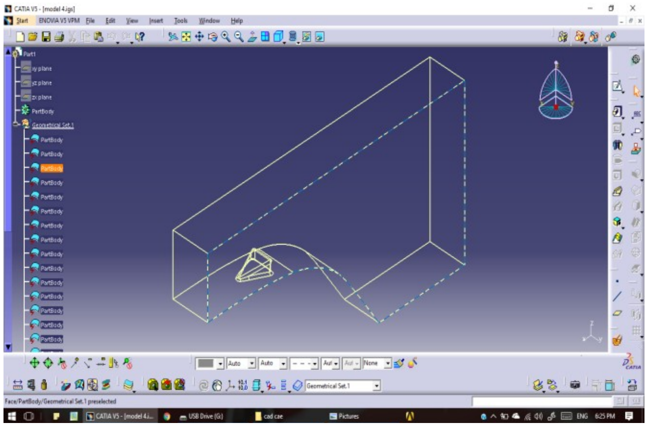
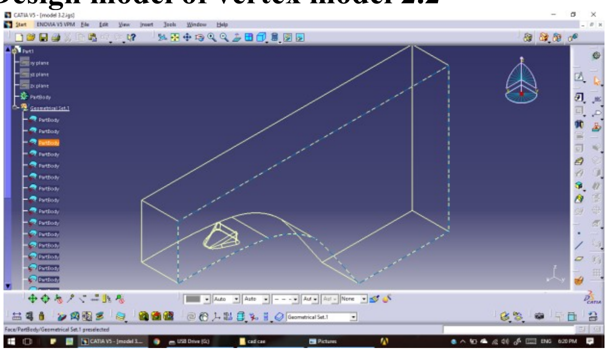
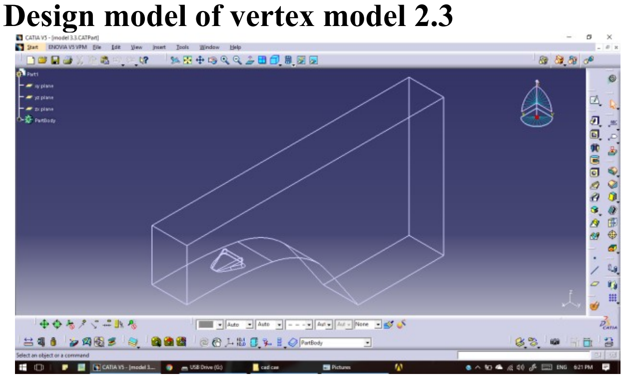


Design model of vertex model 2.2

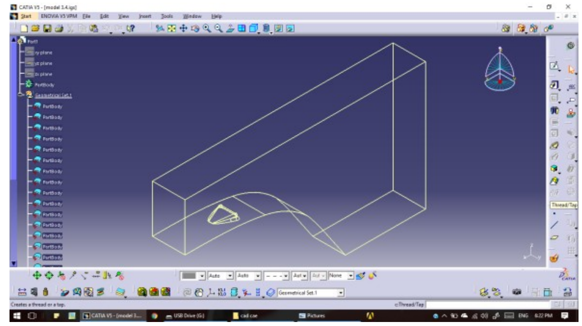


Design model of vertex model 2.3

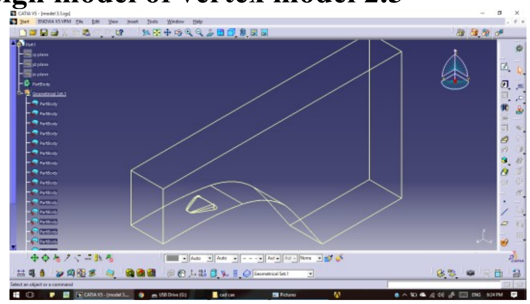


Design model of vertex model 2.4

Model view of inlet



Design model of vertex model 2.5



Average wind speed in India 13 kmph it is equal to 3.61111 mps
Average speed of vehicle in cites is 40 kmph
Maximum Resultant speed of vehicle in cities is 40 kmph + 13 kmph = 53 kmph (it is equals to 14.7222 mps)
Average speed of vehicles in intercity highways is 60 kmph
Maximum Resultant speed of vehicle in intercity highways is 60 kmph + 13 kmph = 73 kmph (it is equals to 20.2778 mps)
Average speed of vehicles in interstate highways is 80 kmph
Maximum resultant speed of vehicles in interstate highways is 80 kmph + 13 Kmph = 93 kmph (it is equals to 25.8333 mps)
Pressure is one atmosphere which equals to 101325 Pascals

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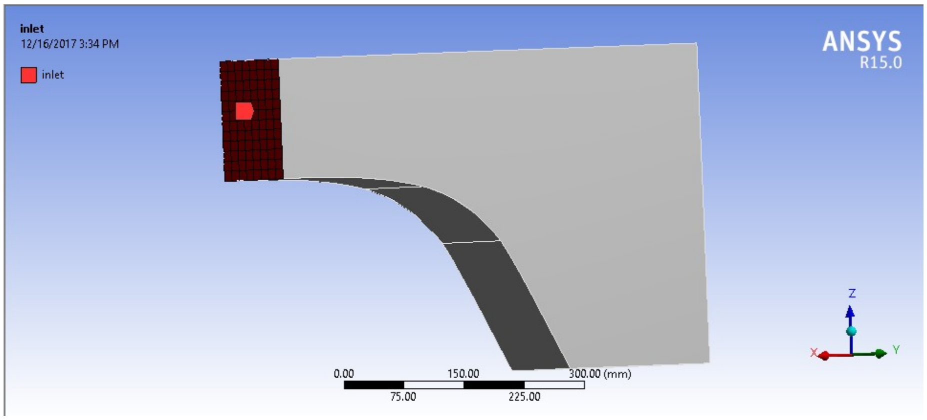


REPORT

Table representing different models at wind speed 20.2778mps

Model At wind speed 14.7222mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model without vertex generator	-3.60E+00	4.83E+01	8.63E-04	1.31E+02	-1.50E+01	2.26E+00	1.06E+00	1.59E+03
model 1	-1.47E+02	2.09E+02	7.43E-03	3.89E+02	-2.51E+01	6.30E+00	1.24E-01	1.17E+05
model 2	-2.36E+02	1.31E+03	1.52E-02	1.38E+03	-2.50E+01	1.15E+01	2.46E-01	8.81E+04
model 3	-2.24E+02	2.36E+02	7.85E-03	4.86E+02	-2.77E+01	8.30E+00	2.23E-01	1.44E+05

Table representing different models at wind speed 20.2778mps

At wind speed 20.2778mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model 1	-1.18E+02	5.33E+01	1.42E-02	2.61E+02	-2.07E+01	9.09E+00	1.42E+00	2.31E+03
model 2	-3.45E+02	3.70E+02	9.45E-03	7.28E+02	-3.41E+01	1.13E+01	1.33E-01	1.87E+05
model 3.3	-5.24E+02	2.78E+02	1.24E-02	7.57E+02	-3.51E+01	1.26E+01	3.70E-01	1.36E+05
model 4	-4.37E+02	4.54E+02	3.65E-02	9.10E+02	-3.80E+01	1.14E+01	2.89E-01	1.99E+05

Table representing different models at wind speed 25.8333mps

at wind speed 25.8333mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model 1	-4.13E+01	1.40E+02	1.36E-02	4.24E+02	-2.63E+01	5.19E+00	1.78E+00	2.94E+03
model 2	-7.34E+02	5.58E+02	2.23E-02	1.33E+03	-4.63E+01	1.11E+01	2.80E-01	2.91E+05
model 3.3	-8.85E+02	4.51E+02	1.07E-02	1.28E+03	-4.57E+01	1.11E+01	5.86E-01	1.81E+05
model 4	-6.96E+02	7.56E+02	1.86E-02	1.53E+03	-4.92E+01	1.59E+01	4.13E-01	2.42E+05

Table representing different models at wind speed 14.7222mps

at wind speed 14.7222mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model 3.1	-2.22E+02	2.10E+02	1.05E-02	4.50E+02	-2.68E+01	1.16E+01	1.73E-01	8.58E+04
model 3.2	-2.79E+02	2.43E+02	2.06E-03	5.27E+02	-2.91E+01	5.88E+00	1.46E-01	8.56E+04
model 3.3	-2.36E+02	1.31E+03	1.52E-02	1.38E+03	-2.50E+01	1.15E+01	2.46E-01	8.81E+04
model 3.4	-2.61E+02	1.22E+02	5.75E-03	3.88E+02	-2.51E+01	5.92E+00	5.94E-01	9.73E+04
model 3.5	-2.16E+02	1.18E+02	9.06E-03	3.57E+02	-2.39E+01	4.54E+00	6.51E-01	1.17E+05

Table representing different models at wind speed 20.2778mps

at wind speed 20.2778mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model 3.1	-4.41E+02	3.87E+02	2.29E-02	8.16E+02	-3.63E+01	1.35E+01	1.95E-01	1.28E+05
model 3.2	-5.58E+02	4.97E+02	1.72E-03	1.06E+03	-4.12E+01	8.76E+00	1.75E-01	1.18E+05
model 3.3	-5.24E+02	2.78E+02	1.24E-02	7.57E+02	-3.51E+01	1.26E+01	3.70E-01	1.36E+05
model 3.4	-5.20E+02	2.36E+02	2.09E-02	7.31E+02	-3.51E+01	1.03E+01	7.95E-01	1.30E+05
model 3.5	-4.24E+02	2.40E+02	1.27E-02	7.98E+02	-3.55E+01	6.42E+00	8.44E-01	1.74E+05

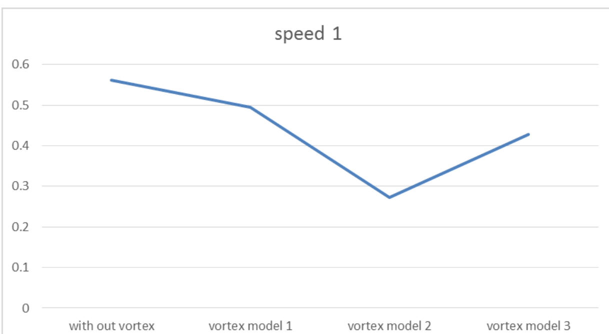
Table representing different models at wind speed 25.8333mps

at wind speed 25.8333mps	Total pressure		Dynamic pressure		X-velocity		Strain rate	
	min	max	min	max	min	max	min	max
model 3.1	-8.18E+02	6.72E+02	2.85E-02	1.38E+03	-4.71E+01	1.52E+01	2.03E-01	1.56E+05
model 3.2	-1.02E+03	8.38E+02	3.82E-03	1.76E+03	-5.45E+01	1.51E+01	2.26E-01	1.48E+05
model 3.3	-8.85E+02	4.51E+02	1.07E-02	1.28E+03	-4.57E+01	1.11E+01	5.86E-01	1.81E+05

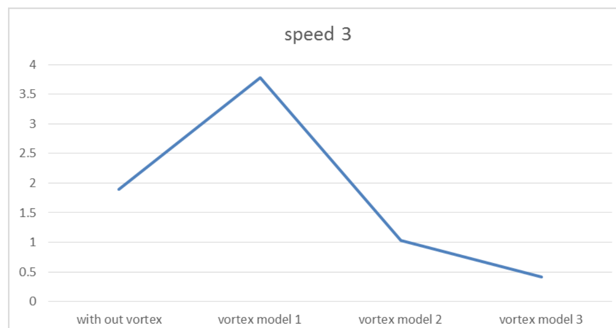
model 3.4	-8.37E+02	3.93E+02	2.58E-02	1.25E+03	-4.52E+01	1.04E+01	9.33E-01	1.76E+05
model 3.5	-7.03E+02	3.59E+02	3.44E-02	1.12E+03	-4.27E+01	9.88E+00	1.17E+00	2.30E+05

Table showing drag force in x-direction for various vertex

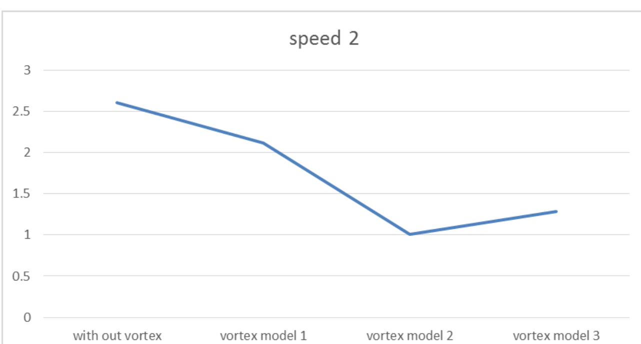
Drag force in x direction in newton's	speed 1	speed 2	speed 3
without vortex	0.561684	2.610895	1.888333
vortex model 1	0.495511	2.114732	3.781421
vortex model 2	0.272552	1.008626	1.025085
vortex model 3	0.427704	1.286723	0.409939



Graph showing drag force in x-direction at speed 1



Graph showing drag force in x-direction at speed 3



Graph showing drag force in x-direction at speed 2

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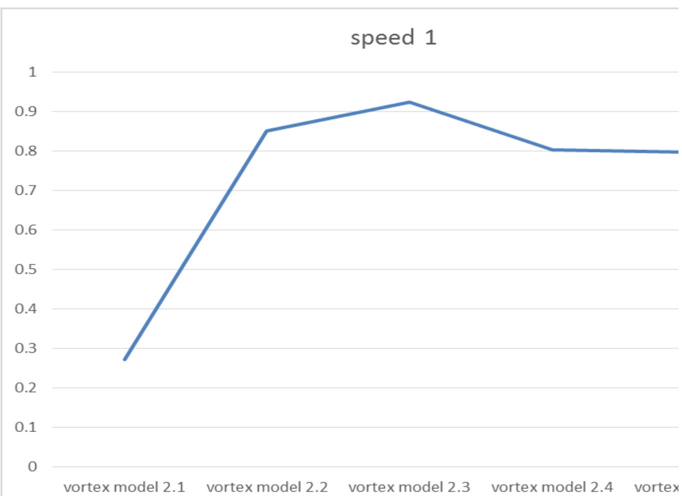
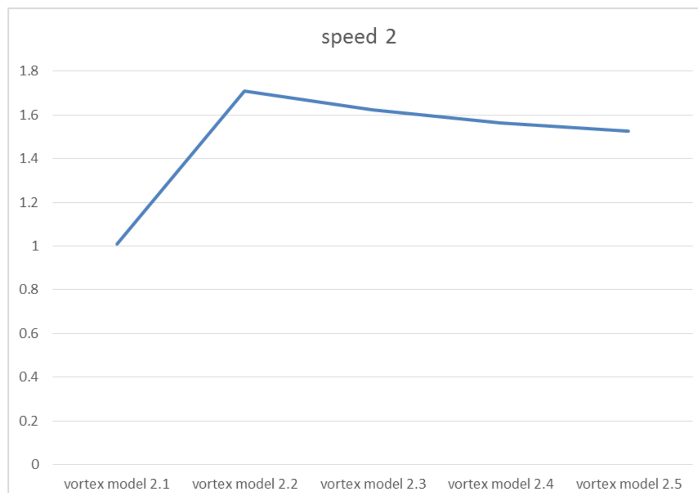
Table showing drag force in x-direction for various vertex models

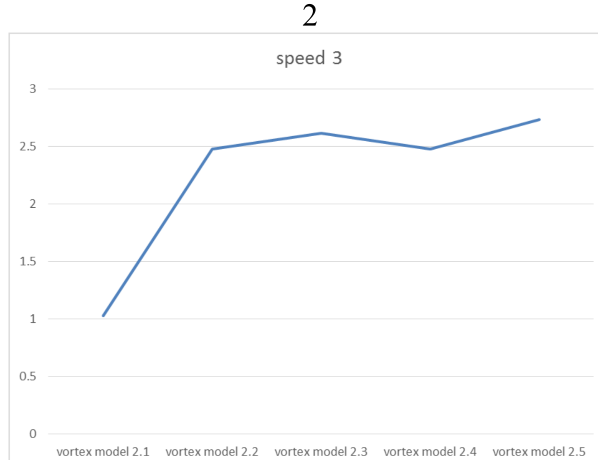
Drag force in x direction in newton's	speed 1	speed 2	speed 3
vortex model 2.1	0.272552	1.008626	1.025085
vortex model 2.2	0.851158	1.708981	2.478753
vortex model 2.3	0.924419	1.625015	2.612897
vortex model 2.4	0.802298	1.563699	2.473084
vortex model 2.5	0.796145	1.52705	2.732052



Graph showing drag force in x-direction at speed 1



Graph showing drag force in x-direction at speed 2



Graph showing drag force in x-direction at speed 3

CONCLUSION

In this thesis CFD analysis is performed on a car cut section with different vortex, vertex generators are developed with varying the angle of nose section, From the results the following observations are made

1. Vertex generator with maximum height shows maximum performance.
2. Moderate conic sections are preferable while designing a vortex generator.
3. In this study lowest drag force Is recorded in vortex generator model 2 with max height.
4. With decrease in height of vortex generator the drag increases.
5. An average of 1.5 N/mm2 is observed between model without vortex and model with vortex model 2.

FUTURE SCOPE

This project can be carried forward by doing some wind tunnel experimentation to study the aerodynamic behavior of vortex by varying geometry, theoretical work could be done for the same.

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