A Comprehensive Analysis on Aerodynamic Characteristics of a MPV Spoiler

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Abstract - Performance, handling, safety, and comfort of a car are significantly affected by its aerodynamic properties. Getting immense power directly from the engine is just not enough to evaluate the performance of the car. Aerodynamic properties must be considered too by analyzing the lift, drag and stability performance of a car. In order to improve a car's aerodynamic properties; aerodynamic features such as the car design itself, rear spoilers, diffuser kits, vortex generators must be taken into account. Rear spoiler acts as an accessory that functions to impair any unintended air flow across the vehicle or in scientific terms, to spoil the 'laminar' flow of the car's aerodynamic movement in motion. This rear placing device creates an area of high pressure to replace the usual low pressure over the trunk resulting in increasing stability of the car. Basically, rear spoilers are fitted at the trunk of a sedan car for its performance; but does it render the exact outcome if a spoiler were fitted in a larger vehicle such as the Multi-Purpose Vehicle (MPV)? Or just for the sake of styling purpose. Thus, this analysis is regarding the effect of rear spoiler on a MPV and the objective of this study is to investigate the aerodynamic characteristic on a MPV vehicle with rear spoiler using CFD software namely (ANSYS). A simple model of the MPV had been drawn using CATIA software; imported to ANSYS software and ultimately to operate the aerodynamic simulation.

Keywords: Vehicle Aerodynamic, MPV, Spoiler, Drag Force, Lift Force, ANSYS Simulation.

I. INTRODUCTION

Nowadays, the normal sedan vehicle including Multi-Purpose Vehicle (MPV) are customized to become sportier and add some wow factor to their ordinary vehicle by the respective owners for multiple reasons. Having outstanding power from the engine leads to immense speeds for which the aerodynamics properties of the MPV by original manufacturer are not sufficient to endeavor desired down force and handling. The safety, comfort, performance, and handling of a vehicle are significantly influenced by the aerodynamic properties too. Additional fittings are mounted to the body such as rear spoilers, vortex generators, air dams, front and rear bumpers, diffusers and many more to channel the airflow in various oriented way and offer greater reduction to drag and enhance the stability. Basically, aerodynamic properties on a vehicle's design is the paramount demeanor of a vehicles design as to harvest steep complexity phenomenon [1] which encompassing an artful iteration and integration of advanced engineering, technology and design aesthetics. Paramount emphasize focused on the aerodynamic properties of any vehicle [2] design as an aerodynamically well-engineered vehicle employs the least force in overwhelm the drag exerted by air and hence flaunts higher performance – cruises faster on lesser fuel consumption [3]. Aside from improvised fuel efficiency, an aerodynamically superior vehicle offers greater handling and stability at respective speed and also minimize unintended interactions [4] on roadways with other vehicles.

II. AERODYNAMICS

Aerodynamics in general is a part of Fluid Mechanics which focuses on forces generated on a body in a flow and involves a lot of calculation in vast properties of the flow such as temperature, pressure, velocity, time and density. In order to calculate the type of forces and moments acting on the bodies, one must first discern the pattern of the flows [5].

Automotive aerodynamics is a type of analysis of the indicative road vehicles involving related properties such as reducing the lift and drag force at high speed and preventing the irregular wind sound. It is also required to produce down force to improvise cornering and traction of a vehicle. Obviously, the vehicle shape does give response on the aerodynamics characteristic.

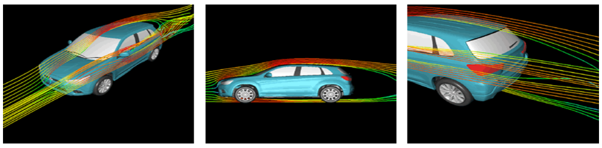

Fig. 1: Aerodynamic stream on a MPV

III. REAR SPOILER

Rear spoiler is an accessory to escalate down force for vehicle mainly on a passenger car. It is an aerodynamic accessory that designed to tarnish any unfavorable air stream across a car. The concentration point is at the rear region, depends on the shape of the rear region either the MPV's is fastback, square back or notchback because not all spoiler can be mounted at any type of MPV. Rear spoiler contributes some major aerodynamics force factors which are lift and drag. The contraction of drag force can saves fuel; moreover, spoiler can also be used to control cornering and stability in motion [6]. Besides that, it even functions to reduce drag and rear-axle upsurge.

Fig.2: MPV with Spoiler
(Proton Exora)

IV. DRAG FORCE

An aerodynamic drag force is the force which opposes the forward motion of the vehicle while in cruise mode and acts externally on the body of the vehicle. The drag force can be measured directly by simply rendering the body subject to analysis of fluid flow, through detailed calibration and measurement of the displacement towards the flow direction. Drag force is usually an undesirable reaction, like friction and most scientist and engineers are trying to minimize by creating alternatives. Reduction of drag is closely associated with fuel efficiency in land, sea and air transport with improved durability and safety of structures subject to high winds, vibration and noise reduction [7]. More sophisticated drag-measuring tools named drag balances uses flexible beams fitted with strain gauges to calculate the drag electronically. Besides that, it can be calculated using the formula (1) as shown below:

$$D_A = \tfrac{1}{2}\, \rho\, v^2\, C_D\, A \qquad (1)$$

Where; C_D = coefficient of Drag

ρ = density of air [kg/m3]

A = frontal area (m2)

v = velocity of vehicle [m/s]

The drag and lift forces depend on the density of the upstream velocity of the wind, air, the upstream velocity of the wind, and the particulars of the body are among other elements which need to be taken into consideration. Therefore, it is convenient to conduct with appropriate dimensionless numbers that represents both the lift and drag characteristic of the body called the drag coefficient. Modern road vehicles such as cars have the value of coefficient of drag, C_D from 0.2 to 0.4 [8]. The smaller the value of C_D, the better the aerodynamic flow of the vehicle. In general, the blunter the vehicle, the higher the drag coefficient. As a result, the percentage of fuel efficiency due to reduced drag is about half the percentage of drag reduction at highway speeds at 110km/h [9].

V. LIFT FORCE

The aerodynamic lift force act vertically to the vehicle body that is perpendicular to the air stream direction. Lift force also generates undesirable enact to the vehicle as it greatly diminishes frictional forces between the asphalt and tyre of the vehicle and dramatically changes the handling characteristic of a vehicle. The lift force can be calculated using the formula (2) as shown below:

$$L_A = \tfrac{1}{2}\, \rho\, v^2 C_L\, A \qquad (2)$$

Where; C_L = coefficient of Lift

ρ = density of air [kg/m3]

A = frontal area (m2)

v = velocity of vehicle [m/s]

Some accessory such as the spoilers and inverted airfoils on vehicles are created for the purpose of avoiding lift or even generating negative lift to improvise control and traction of the vehicle. Some early race cars actually 'took off' at high speeds as a result of the lift generated, which alerted the engineers to come up with solution on ways to greatly reduce lift in future design [8].

VI. LAMINAR & TURBULENT FLOW

For instance, being around smokers; it is discerning that the cigarette smoke afloat in a smooth plume for the first few seconds and stars fluctuating randomly in all directions as it continues to rise. Likewise, a careful inspection of an air flow reveals that the flow is streamlined at low velocity but turns chaotic as the velocity increased above a critical value as shown in Figure 3 below. The flow regime in the first region is said to be laminar flow characterized by smooth streamlines and highly ordered motion; and turbulent flow in the second region where it is characterized by velocity fluctuations and highly disordered motion.

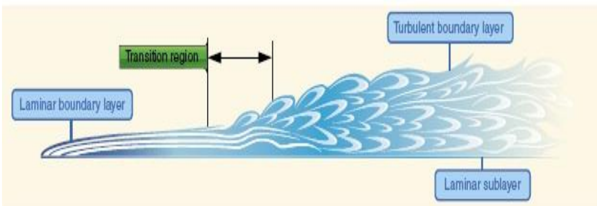

Fig. 3: Turbulent and Laminar Flow

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The transition from laminar to turbulent flow does not occur abruptly, rather it occurs over some region in which it fluctuates between the laminar and turbulent transitions before it fully becomes turbulent.

VII. METHODOLOGY

The main software used in this project are the computer aided software namely CATIA for designing and ANSYS software for Computational Fluid Dynamics prospect. All the relevant parameters are set according to the given limitation.

Next, modelling in CATIA software using a type of MPV model as a reference. Three different types of MPV model need to be figured using CATIA software; one without spoiler named MPV, with spoiler 90º angle with 20cm length and 8cm in height (Proton's original OEM specification) named MPVs and the last with enlarged spoiler which were designed much wider from the original OEM's specifications 100º angle, 50cm length and 8cm in height named MPVss. Then, all these models must be exported to ANSYS software to operate the CFD stream for all the MPV model for analyzing. The CFD stream need to be observed attentively and all the relevant details, result, graph and data must be documented for further discussion and analyzing usage.

VIII. MODELLING

Firstly, a MPV type vehicle need to be chosen as a reference to be modelled in the software. In this project, a locally assembled brand; Proton Exora are chosen as a reference and all the parameters [10] are obtained and stated as in Figure 4 below: -

TECHNICAL SPECIFICATIONS & PRODUCT FEATURES

		1.6L AT (M-LINE)	1.6L AT (H-LINE)
ENGINE	Model	CamPro CPS 4 Cylinder, DOHC 16V	
	Maximum Output (hp [kW]/rpm)	125 hp [93 kW] / 6,500 rpm	
	Maximum Torque (Nm/rpm)	150 Nm / 4,500 rpm	
	Fuel Tank Capacity (l)	55	
PERFORMANCE	Maximum Speed (km/h)	165	
	Acceleration 0-100km/h (sec)	15.5	
CHASSIS	Power Steering	Hydraulic	
	Suspension - Front/Rear	MacPherson Strut / Torsion Beam	
	Brake - Front/Rear	Ventilated Disc / Drum	
	Tyres & Rims	195/65 R15, Alloy	
DIMENSIONS & WEIGHT	Overall Length x Width x Height (mm)	4592x1809x1691	
	Wheelbase (mm)	2730	
	Kerb Weight (kg)	1422	1442
SAFETY & SECURITY	Dual Airbags with Pre-tensioner Seat Belt	√	√
	Anti-Lock Braking System with EBD + Back up EBD (BEBD)	√	√
	Immobilizer System	√	√
	Central Door Lock	√	√
	Alarm System & Keyless Remote Entry	√	√
	Reverse Sensors	√	√
OTHER FEATURES	Radio with CD, MP3 Player, WMA, Bluetooth	√	√
	Front & Rear Power Window	√	√
	Electric-Remote Side Mirror	√	√
	Driver's Seat Height Adjuster	√	√
	Steering Wheel with Audio Switches	√	√
	Seat and Door Trim Finishing	Fabric	Leather
	Front Fog Lamps	-	√
	Rear Spoiler	-	√
	Front Seat Armrest	-	√
	Cruise Control	-	√
	Navigation System	-	√
	DVD/LCD Monitor with SD/MMC Slot & USB Port	-	√
	Tinted Glass	-	√

Fig. 4: Proton Exora Technical Specifications & Features

Where;

Overall length: 4592mm
Width: 1809mm
Height: 1691mm
Wheelbase: 2730mm

As the above parameters obtained, now it is ready to model a simple structure of the vehicle with three different models in CATIA software. The scale of the modelling is set to be 1:10. The modeled structures are shown in the Figure 5, Figure 6 and Figure 7 as below: -

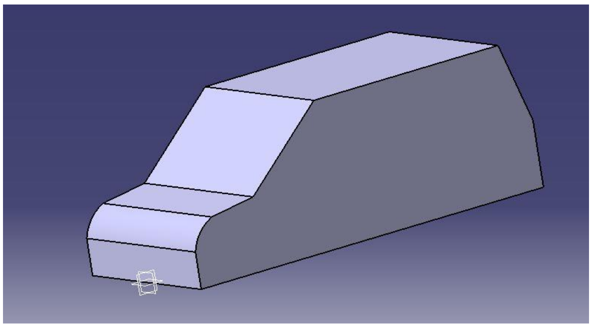

Fig. 5: MPV Model

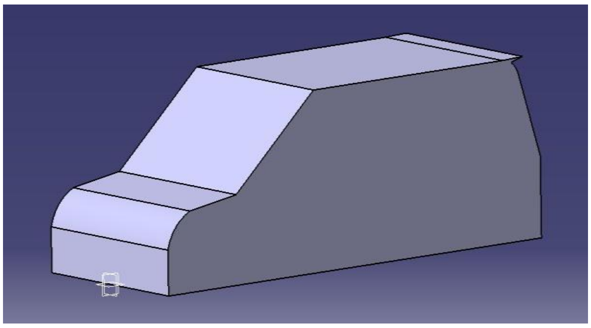

Fig. 6: MPVs Model

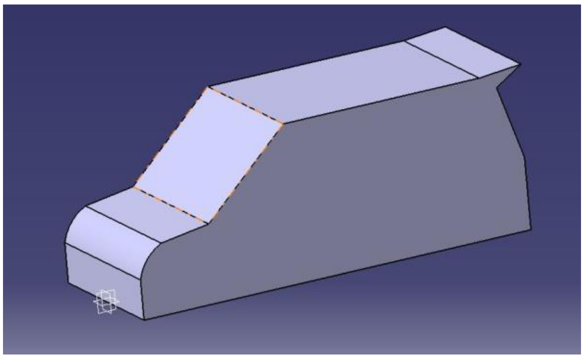

Fig. 7: MPVss Model

IX. ANALYZING IN CFD SOFTWARE (ANSYS)

ANSYS software is mainly used for analyzing the designed model with comprising simulation which enables any individual or organizations to efficiently analyses how the product or model operates and responses in virtual environment. Besides that, it is also known to simulate interactions and properties of elements such as vibration, physics, structural, Computational Fluid Dynamic flow, and heat transfer for professionals such as engineers, researchers and scientist.

Furthermore, ANSYS software has the ability to determine and improve any anemic points and foreseeing probabilities of complications which are both possible with its 3-Dimension simulation. Therefore, in order to operate this software, one must learn the fundamental principles and explore the software by himself. Detail steps and procedures are provided in its tutorial packages. After the all the MPV models were obtained from CATIA software, it must be imported to ANSYS software in order to operate the CFD simulation. All the parameters and variables are stated according to the limitation explained earlier. The design will be further analyzed and as the data interpreted, the result will be composed due to the analysis summarization.

X. ANSYS SIMULATION

There are 2 different methods in analyzing the aerodynamics CFD stream of a vehicle which is either using conventional "Wind-Tunnel" or the other one is by running the vehicle model in ANSYS simulation which is this project based on. As the ANSYS user-interface appears, the system chosen were Fluid-Flow (FLUENT) and thus the related parameter/process is shown as in Table 1 below and the settings are same for all the 3 models. All the settings gained are referred from ANSYS tutorial [11].

Table-1: ANSYS properties and settings

ANSYS Properties	Settings
Analysis System	Fluid Flow (FLUENT)
Geometry	
FD3, x	1000mm
FD4, y	90mm
FD5, z	0mm
FD6	-2500mm
FD7	-700mm
FD8	700mm
Meshing Process	
Physics Preference	CFD
Use advanced size function	On proximity & Curvature
Relevance Center	Fine
Initial size seed	Active assembly
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Proximity Accuracy	0.5
First Aspect Ratio	5
Growth Rate	1.20
Smoothing iterations	10
Maximum layers	5
Problem Setup	
Type	Pressure based
Velocity formulation	Absolute
Time	Steady
Models	Viscous, Realizable k-epsilon, Non equilibrium-wall function
Materials	
Fluid	Air
Solid	Aluminium
Boundary Conditions	
Velocity inlet	x-velocity = -40m/s Turbulent Intensity = 1% Turbulent Viscosity Ratio = 10
Pressure outlet	Backflow Turbulent Intensity = 5% Backflow Turbulent Viscosity Ratio = 10
Reference Value	
Area (m^2)	0.0305141 *for MPV
Density (kg/m^3)	1.225
Enthalpy (J/kg)	0
Velocity (m/s)	40
Viscosity (kg/m-s)	1.7894e-0.5
Ratio of Specific Heat	1.4
Solution Method	
Scheme	Coupled
Gradient	Least Square Cell Based
Pressure	Standard
Momentum	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Turbulent Dissipation Rate	Second Order Upwind
Solution Control	
Flow Courant Number	50
Momentum	0.25
Pressure	0.25
Density	1
Body forces	1
Turbulent Kinetic Energy	0.8
Turbulent Dissipation Rate	0.8
Turbulent Viscosity	0.95
Solution Initialization	
Calculation Initialization	100
Number of Iteration	200

XI. RESULT AND DISCUSSION

The simulation performed for all the three different models (MPV, MPVs and MPVss) and the related graphical results were relatively obtained. The relevant element/characteristic of the vehicle's aerodynamic is being tested such as the contours of pressure, total pressure distribution, maximum velocity and the turbulence kinetic energy. The tests are conducted for all the 3 models with various speeds as stated below but the graphical simulation only shows results for (velocity, V = 40m/s = 144km/h) because spoiler performs/responses better at high speed [12].

XII. MULTI PURPOSE VEHICLE WITHOUT SPOILER (MPV)

Below are the graphical results of the simulation on MPV model for velocity, V = 40m/s. The maximum pressure is 1152pa, maximum velocity is 61m/s and the Maximum Turbulence Kinetic Energy is 192.44m^2/s^2. Figure 11 reflects the turbulence which occurs exactly at the rear compartment of the MPV model, thus increasing drag.

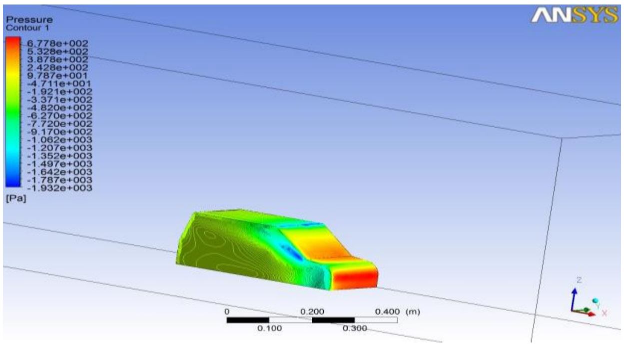

Fig. 8: Contours of Pressure (MPV)

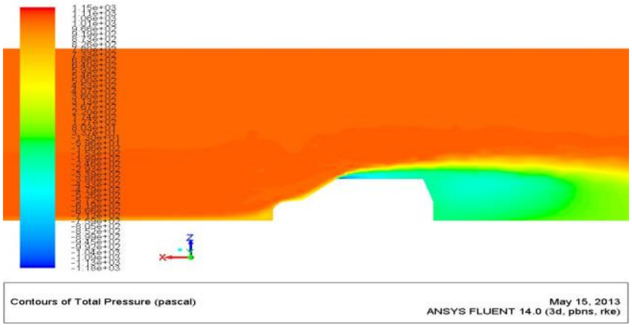

Fig. 9: Contours of Total Pressure (MPV)

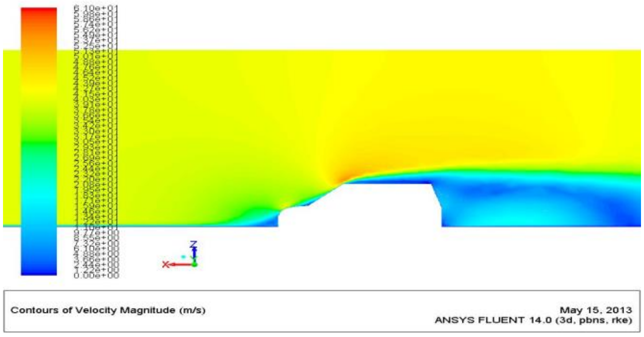

Fig. 10: Contours of Velocity Magnitude (MPV)

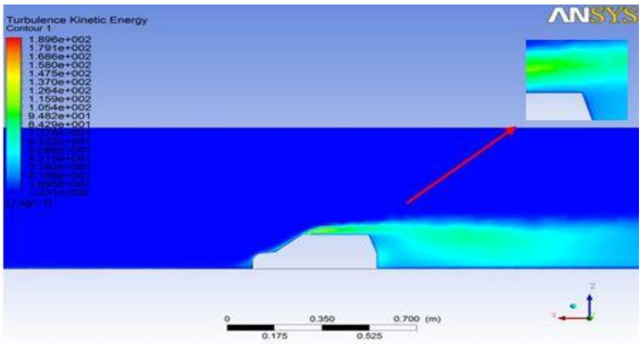

Fig. 11: Contours of Turbulence Kinetic Energy (MPV)

XIII. MULTI-PURPOSE VEHICLE WITH SPOILER (MPVS)

Below are the graphics results of the simulation on MPVs model for velocity, V = 40m/s. The maximum pressure is 1285pa, maximum velocity is 60.8m/s and the Maximum Turbulence Kinetic Energy is 200.65m^2/s^2. On Figure 15, the turbulence occurs further from the rear compartment due to the spoiler of the MPVs model, thus decreasing drag compared to the MPV model.

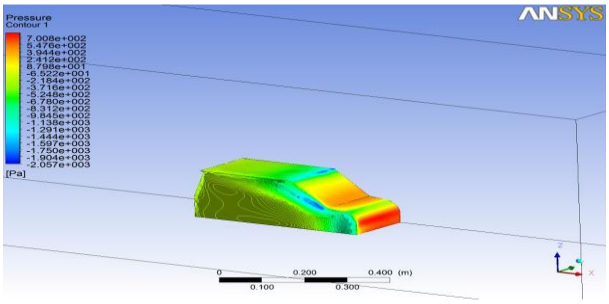

Fig. 12: Contours of Pressure (MPVs)

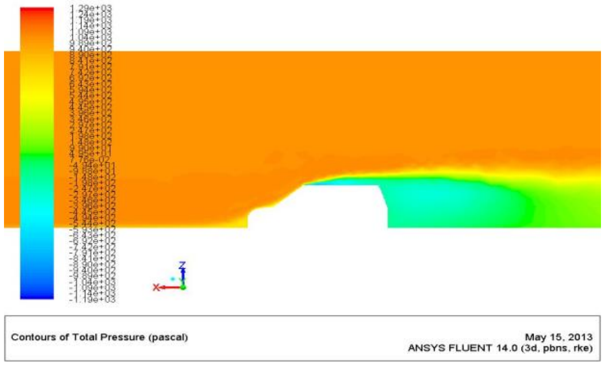

Fig. 13: Contours of Total Pressure (MPVs)

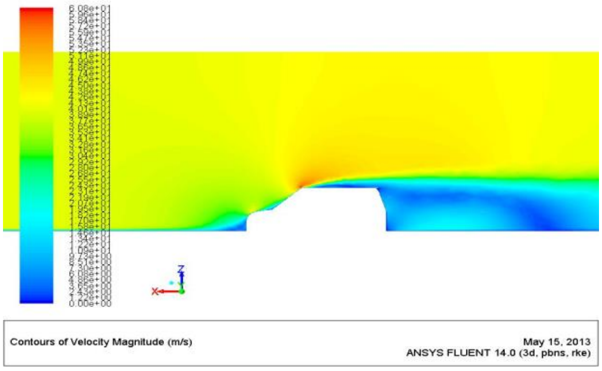

Fig. 14: Contours of Velocity Magnitude (MPVs)

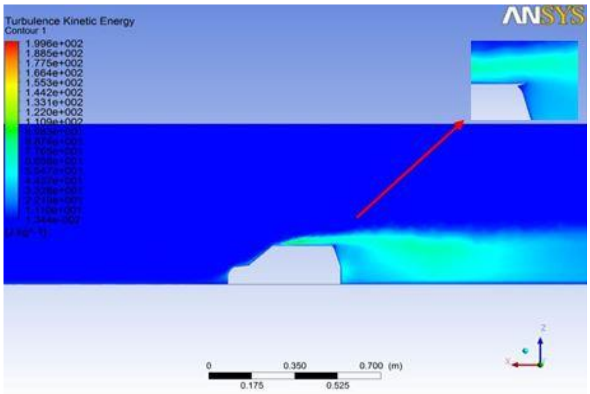

Fig. 15: Contours of Turbulence Kinetic Energy (MPVs)

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XIV. MULTI PURPOSE VEHICLE WITH RESTRUCTURED SPOILER (MPVss)

Below are the graphics results of the simulation on MPVss model with enlarged restructured spoiler of (10$0^{\circ}$ angle, 50cm length & 8cm height) with velocity, V = 40m/s. The maximum pressure is 1155pa, maximum velocity is 62.8m/s and the Maximum Turbulence Kinetic Energy is 187.37m2/s2. On Figure 19, the turbulence dissipates even further from the rear compartment due to the structured spoiler of the MPVss model, thus decreasing more drag and enable to travel faster compared to both the MPV & MPVs model.

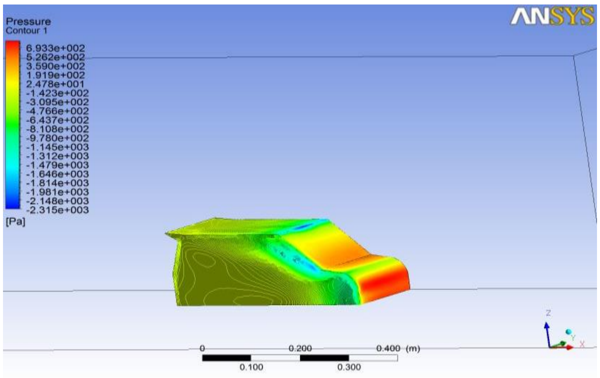

Fig. 16: Contours of Pressure (MPVss)

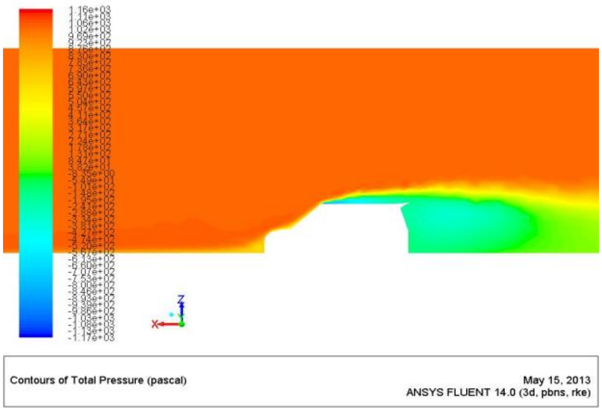

Fig. 17: Contours of Total Pressure (MPVss)

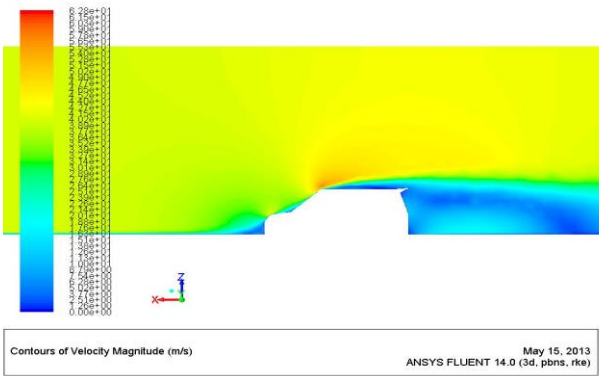

Fig. 18: Contours of Velocity Magnitude (MPVss)

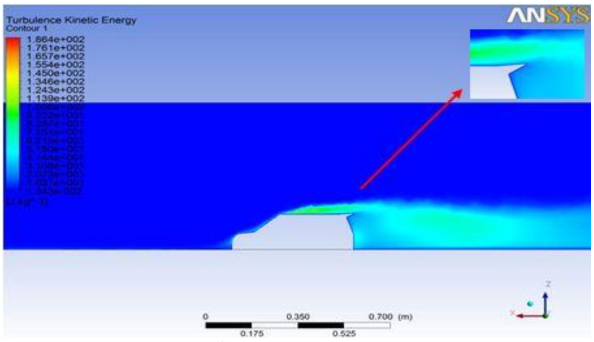

Fig. 19: Contours of Turbulence Kinetic Energy (MPVss)

GRAPHICAL ANALYSIS

From the graphical analysis result above, Figure 8, 9, 12, 13, 16 and 17 dictates the contours of static pressure on the vehicle model's body and symmetry. The stagnation point can be observed clearly at the front area of the vehicle model where the red colored contour happens to be high pressured region. When flow reaches at the rear end due to formation of wakes and turbulence in free stream flow; the pressure drops and the vehicle experience a net backward force. The total pressure for the 3 cases of vehicle model are obtained and the MPVs model shows the higher amount of pressure compared to the other 2 models.

Figure 10, 14 and 18 shows the velocity contours on symmetry wall. The small red area shows the velocity has increased to maintain continuity and the blue contours appears to be a low velocity region. The velocity flow drops at the frontal area of the models due to some sharp edges/curves and it suddenly increase to the red color contour at top of the models. It shows the separation of flow on that region. As the flow continues on top of the models, wake occurs at the rear section of all the three models but fewer wakes obtained on the MPVss model resulting in minimum pressure drag. This indicates that the MPVss experience less drag force and able to travel/accelerate faster compared to MPV and MPVs model.

Figure 11, 15 and 19 shows the contours of turbulence kinetic energy. For all the cases, the turbulence starts at the front top section of the models due to the sharp edges of the model's front windshield. From the existence of the rear spoiler, the turbulence flow can be dissipated further from the rear compartment of the vehicle model and allowing the wake to take effect. This can greatly reduce pressure drag but doesn't have much effect on the lift force. The MPVss model experience lower turbulence kinetic energy compared to the MPV and MPVs model. Accordingly, it is evident that a spoiler really acts as a drag reduction device to reduce drag force even on a multi-purpose vehicle.

XIV. MODEL COMPARISON

Below are the data and results retrieved from the ANSYS simulation and in order to differentiate; tables and graphs are organized for better justification. The drag force and lift force obtained were auto-calculated from the analysis and demonstrates the same value using manual formula

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calculation. All the related data, results, table and graph are as shown as below: -

For all the 3 model (MPV, MPVs and MPVss), simulation are analyzed using various speed, which is at 10m/s (36km/h), 20m/s (72km/h), 30m/s (108km/h) and 40m/s (144km/h) in order to obtain all the relevant element such as the drag force, drag coefficient, lift force & lift coefficient. Besides that, this method is important to analyze at which speed the rear spoiler of the vehicle model can really performs.

Table-2: Properties at Velocity, V=10m/s

At Velocity, V = 10m/s

Description / Case	DRAG FORCE, F_D (N)	LIFT FORCE, F_L (N)	DRAG COEFFICIENT C_D	LIFT COEFFICIENT C_L
1. MPV	0.89	1.46	0.47	0.78
2. MPVs	0.90	1.44	0.48	0.76
3. MPVss	0.90	1.45	0.45	0.76

Table-3: Properties at Velocity, V=20m/s

At Velocity, V = 20m/s

Description / Case	DRAG FORCE, F_D (N)	LIFT FORCE, F_L (N)	DRAG COEFFICIENT C_D	LIFT COEFFICIENT C_L
1. MPV	3.69	5.8	0.49	0.78
2. MPVs	3.65	5.7	0.48	0.77
3. MPVss	3.46	6.0	0.45	0.78

Table-4: Properties at Velocity, V=30m/s

At Velocity, V = 30m/s

Description / Case	DRAG FORCE, F_D (N)	LIFT FORCE, F_L (N)	DRAG COEFFICIENT C_D	LIFT COEFFICIENT C_L
1. MPV	8.07	13.23	0.48	0.79
2. MPVs	8.18	13.06	0.48	0.77
3. MPVss	7.73	13.36	0.45	0.77

Table-5: Properties at Velocity, V=40m/s

At Velocity, V = 40m/s

Description / Case	DRAG FORCE, F_D (N)	LIFT FORCE, F_L (N)	DRAG COEFFICIENT C_D	LIFT COEFFICIENT C_L
1. MPV	14.58	23.04	0.49	0.77
2. MPVs	14.46	23.47	0.48	0.78
3. MPVss	13.70	23.80	0.45	0.77

The sample calculation to obtain drag force (F_d) and lift force (F_l) for model MPV based on the obtained drag and lift coefficient from simulation results at velocity, V = 40m/s are shown as below, and for the rest are calculated automatically from the simulation and the relevant graph are plotted below as well: -

Air density, ρ is fixed at 1.225 kg/m^3
Coefficient of Drag, C_d = 0.49
Coefficient of Lift, C_l = 0.77
Model MPV at velocity, V = 40m/s
Frontal area of MPV model, A = 0.0305m^2

$$F_D = \frac{1}{2}\rho V^2 A C_d$$

$$F_D = \frac{1}{2}(1.225)(40^2)(0.0305)(0.49$$

= 14.6N

$$F_l = \frac{1}{2}\rho V^2 A C l$$

$$F_l = \frac{1}{2}(1.225)(40^2)(0.0305)(0.77)$$

= 23.02N

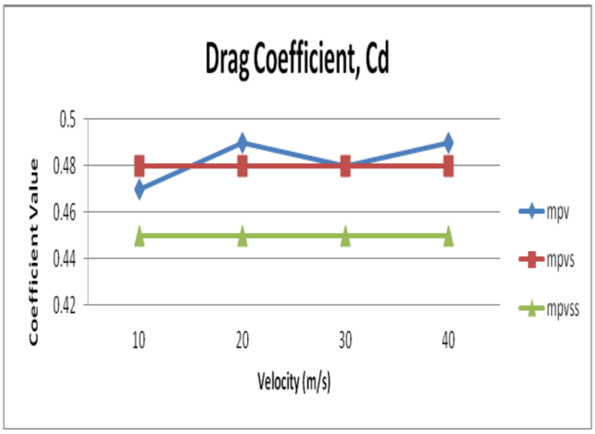

Fig. 20: Model Drag Coefficient

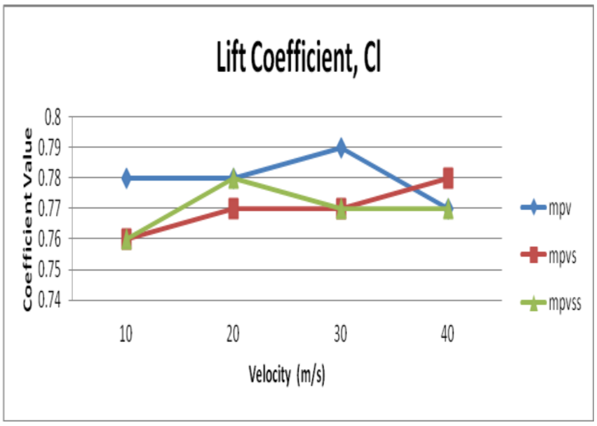

Fig. 21: Model Lift Coefficient

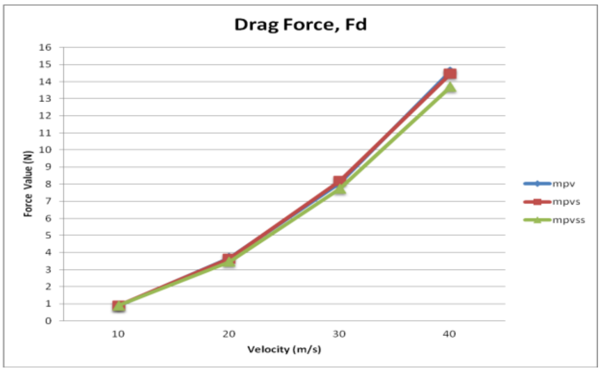

Fig. 22: Model Drag Force

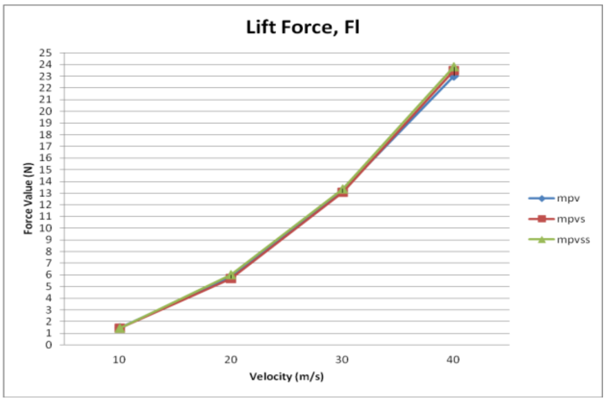

Fig. 23: Model Lift Force

In distinction to the complete table and graph obtained from the analysis result for all the 3 models, it is evident that the model MPVss reduces drag force greater compared to the both models respectively. From the illustrated table above (Table 2, 3, 4 and 5), it clarifies that the spoiler only responses on a vehicle at high speed as it only reducing drag force and drag coefficient beginning from 20m/s and up to 40m/s. Thus, the higher a vehicle's speed, the greater it reduces the drag for model MPVss. Consequently, the lift force and life coefficient for all the 3 models remains more or less the same at various speeds according to the table. Even in the graph obtained above (Figure 20, 21, 22 and 23) the MPVss model shows that both the drag force and drag coefficient are reduced greatly compared to MPV and MPVs but nothing changes much on lift force and lift coefficient for all the vehicle models.

Additionally, the drag force value can be used to calculate the fuel consumption [13] by using the formula of fuel economy/consumption as shown in Figure 24 below: -

$$\frac{L}{100} = 0.008051 \times F_D \quad \text{·Fuel Consumption Formula}$$

Fig. 24: Fuel consumption formula

Sample calculation for velocity, V = 40m/s

Drag force for MPV = 14.58N
Drag force for MPVs = 14.46N
Drag force for MPVss = 13.7N

a. Fuel consumption for MPV:

$$\frac{L}{100} = 0.008051 \times 14.58$$

= 0.120L/100km

b. Fuel consumption for MPVs:

$$\frac{L}{100} = 0.008051 \times 14.46$$

= 0.116L/100km

c. Fuel consumption for MPVss:

$$\frac{L}{100} = 0.008051 \times 13.7$$

= 0.110L/100km

The value of fuel consumption for the all the 3 cases of the vehicle model are obtained and clearly shows that with reduced drag force, fuel consumption of a vehicle can also be greatly reduced per 100km and thus spoiler can even functions as an alternate fuel saving kit at high speed cruising. Therefore, the structured spoiler on a multi-purpose vehicle (MPVss) is the best model among MPV and MPVss in terms of reducing the drag force, drag coefficient and ultimately reducing fuel consumption at high speed cruising.

XV. CONCLUSION

In conclusion, based on the result attained from the simulation analysis, both the conceptual and theoretical aspects of the aerodynamic characteristic on the vehicle model are well acquainted. The spoiler unit on a multi-purpose vehicle does not acts just as a cosmetic purpose or for 'sportier looks' only nevertheless it legitimately performs at high speed cruising, reducing the drag force on the vehicle thus increasing overall vehicles performance. Therefore, it also evident as the multi-purpose vehicle with structured rear spoiler (MPVss) travels at high speed eventually saves fuel consumption per 100km compared to multi-purpose vehicle with rear spoiler / original full specification OEM (MPVs) and multi-purpose vehicle without rear spoiler (MPV). It also undeniable that with larger spoiler mounted at the rear compartment of the vehicle, the more it reduces drag force and increases the vehicles performances. This can be seen as even though the (MPVs) model does reduces drag in a smaller margain compared to (MPV) model, but the superior (MPVss) model can greatly reduces both the drag force and drag coefficient compared to (MPV) model.

Besides that, the result also shows that there is nothing much changes on the lift force. This is due to the weight of the car itself; with 1422kg and since multi-purpose vehicles are normally heavy, the lift force cannot be reduced much even with mounted rear spoiler and thus the lift force on all the 3 models of the vehicle remains more or less the same. In conjunction with the analysis and results obtained, the objectives of this project are very well achieved, since the analysis result are well associated with the multi-purpose vehicle's rear spoilers characteristic alligned with the theoretical and conceptual approach of a vehicle aerodynamics.

XVI. RECOMMENDATION

As for the recommendation in future studies, the vehicle model must be modelled entirely by considering the wheel, side-mirrors and other element on the vehicle to construct better and precise readings/results. It also can be simulated using other properties such as k-omega model, RNG k-epsilon model and other CFD model to observe and differentiate the results on the aerodynamic characteristics of the rear spoiler. During the meshing part of the vehicle model, other properties may be considered and revised such as the relevance centre, smoothing and transition to gain a better mesh of the vehicle model. The iteration number of the simulation on analyzing the vehicle model might be also increased to 1000 iterations or above if possible; to gain an accurate readings and better resolution of the vehicle's aerodynamics.

Lastly, the experiment on analyzing the aerodynamics of a rear spoiler on a multi-purpose vehicle for future studies can also be held in the real-time "Wind-Tunnel" model and compare the result obtained with the result by simulation analysis. This can improve the accuracy of the parameters and results of the aerodynamics characteristic of the rear spoiler on a multi-purpose vehicle. Besides that, there are other types of rear spoilers or drag-reduction devices that can be installed and analyzed in order to study, experiment & analyze the additional decreasing the value of drag coefficient and aerodynamic drag force on a multi-purpose vehicle such as the Wing-type, Diffuser-type and even 'Vortex Generators'.

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