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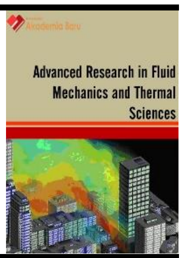

Reconstruction of 3D Models Using Close-Range Photogrammetry Method for CFD Applications

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ABSTRACT

The recent developments of close-range photogrammetry techniques have become one of the most influential methods for various purposes for a wide variety of applications. These highly affordable and accurate digital imaging techniques have not only provided reliable results but faster 3D model reconstruction period. With that in mind, the advances in computational fluid dynamics (CFD) have also provided an alternative solution to the fluid flow behavior investigations, especially in the aerodynamic applications. Therefore, the main objective of this paper is to present the used of close-range photogrammetry technique in creating a 3D imaging of a small-scaled car for CFD modeling. The digital model is created in Autodesk ReCap software, where after it is imported into Solidworks to perform the airflow simulation analyses. The behavior of flow structures across the model are simulated under steady-state conditions and have shown clear results of the pressure and velocity distribution. These results have provided useful information on the strong relation of the aerodynamic car model geometry with the flow separation phenomenon. Moreover, the obtained CFD results highlight the interesting flow physics of roll-up vortices formation. Therefore, the minimum and maximum vortices created by the 3D model car are 0.04 s^{-1} and 1555.59 s^{-1} respectively with the velocity airflow of between 0 and 50 ms^{-1}.

1. Introduction

The popularity of three-dimensional modeling in automotive engineering field has shown a growing tendency [1-3]. In the automotive areas of applications, the automotive design investigation with regard to parts geometries accuracy, safety aspects and environmental performances is hugely important [3]. These studies are usually conducted using conventional methods and equipment, for example, tactile contact methods using coordinate measuring machine (CMM) and robotic arms, and non-contact methods using 3D laser scanner, laser triangulation, stereo vision, and coded pattern

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projection [4, 5]. However, these traditional methods are very expensive to execute and difficult for data analyses [6]. Although the developed digital models via these methods have good precision, the reconstruction of the 3D models require very long processing time and failure can occur during the processing period [7, 8]. Therefore, close-range photogrammetry techniques have been introduced into today's technology as an alternative approach for developing the digital models [9, 10]. The techniques not only provide similar accuracy and precision as the previous methods but are more user-friendly, cheaper, do not require very skilful operator and one of the major advantages is shorter digitizing period [11, 12]. Moreover, this contactless technique has offered an ample variety of simulation studies and new marketing channels in various industries especially in the automotive industry [13, 14].

In the automotive engineering field, engineers usually investigate the finished products either for validation and verification purposes using software tools or any other needed modification [14, 15]. With this in mind, to develop the correct models for in-depth studies through CAE simulations are not an easy task and time consuming. However, modern 3D data acquisition technology using simply photogrammetry tool can aid to obtain reliable feature extraction, evaluate performances and qualities, and achieve higher measurement accuracy [16, 17]. In addition, the photogrammetry reconstruction methods are fostered by the developments of both computer hardware and software, and computing technologies [18]. Besides, using CFD simulation of the photogrammetric models for vehicle design purposes can largely reduce the relying expensive of wind tunnel test for aerodynamic studies in the automotive field [19]. Therefore, this article focuses on developing a 3D model of a sample car (small-scaled model) using close-range photogrammetry technique for Computational Fluid Dynamics (CFD) applications. Additionally, the photogrammetric data acquisition procedure and CFD results are outlined in the following sections. Moreover, future works for digital and CFD modeling are proposed.

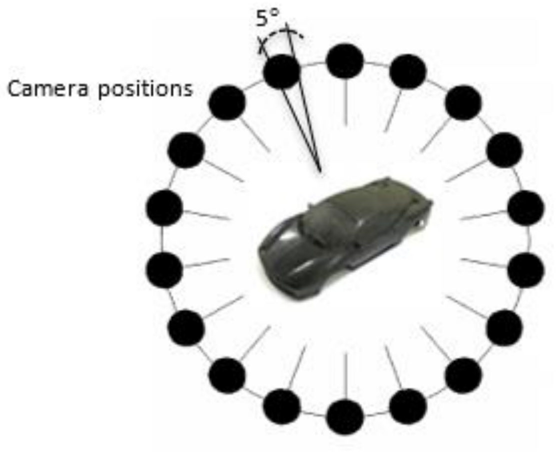
2. Methodology

This section describes the airflow investigation procedure for the case study of a 3D small-scaled car model. The workflow begins by reconstructing the 3D car model using Autodesk's ReCap software via close-range photogrammetry method. The developed CAD model is then exported into Solidworks software to perform the airflow simulations. Focused will be given on how does the employed photogrammetric technique has impacted the CFD analyses in terms of the model geometrical consistency and accuracy, and convenient operation.

2.1 Photogrammetric Modeling
2.1.1 Data acquisition and digital workflow

The photogrammetry procedure works by taking images from every angle of the object in a full loop. Additionally, the images for a realistic 3D model reconstruction can be obtained by using any consumer digital cameras or even smartphone cameras [27]. The digitizing process can also be done in several free for non-commercial photogrammetry software, which offers various powerful tools for 3D modeling such as 3DF Zephyr Free, COLMAP, Multi-View Environment (MVE) and Autodesk's ReCap [27].

In this research, the preliminary test is conducted by taking a total set of 144 images around the sample small-scaled car model using an iPhone 7 Plus smartphone camera. The images are shot at every 5° angle in full loops from two different heights, top and bottom rows as shown in Figure 1. Moreover, they are shot with the camera's technical specification as tabulated in Table 1.



(a)

(b)

Fig. 1. Images acqusition for photogrammetry: (a) taken in complete loops, (b) taken from top and bottom rows

Table 1
Camera's technical specifications

Specifications	iPhone 7 Plus camera
Resolution sensors	12 MP
Aperture	f/1.8
HDR mode	Activated
Picture size	4000x3000
Digital tele	1x
Sensitivity auto	ISO 100
Exposure time	1/6 s
Focal length	3.99 mm

Above all, conditions during the photographing session have to be taken into account. The images have to be shot in good exposure time with a soft-lighted surrounding. Also, ensuring that the object has lower reflections is important [20]. This is because failure can occur during the digitizing stage in the photogrammetry software as poor quality visual models can be resulted [21].

2.1.2 Photogrammetric product

Later, the selected images are uploaded to the Autodesk's ReCap Photo software to develop the digital model of the car. The modeling on ReCap is chosen because the software has a convenient user-interface that allows users especially non-photogrammetrists to execute any photogrammetry project easily. Additionally, coordinates of imaged points are not the necessities in the ReCap Photo software and the major benefit of the software is that the 3D models can be built based on non-metric camera images. Therefore, any type of camera can be used to take multiple images of an object without calibrating the camera by a test-field, which is really complicated in certain scenarios. Thus, Figure 2 shows the reconstructed 3D model of the car in the Autodesk ReCap software.

Fig. 2. 3D photogrammetric car model

Moreover, enhancements on the prepared CAD model for smoother-constructed geometry can be done in software such as MeshMixer to obtain well efficient simulation. Therefore, optimizing the model is an optional step if the meshes in the regions of interest on the model require repairing or filling. In this research, the photogrammetric car model is re-triangulated and the side mirrors are cropped. This is done to enhance the meshing surfaces of the model and to reduce calculation errors during CFD analyses.

2.2 Computational Fluid Dynamics (CFD) Simulation Process

After reconstructing the digital car model in the Autodesk ReCap software via the photogrammetry technique, the 3D CAD model is imported and launch to Solidworks software. The model is made stationary and boundary conditions are set. The CFD analysis of external flow geometry over the model is investigated and closed cavities are considered. This is to exclude any internal space and cavity without flow conditions. Moreover, other physical features such as radiation and heat conduction are not taken into account as this preliminary research only emphasizes on the airflows analysis. The final step is to create a computational domain shape for the flows all around the car model. Additionally, the domain shape is made larger than the CAD model itself for better aerodynamic analysis. Therefore, Figure 3 show the 3D CAD model of the car and its computational domain shape in the CFD software.

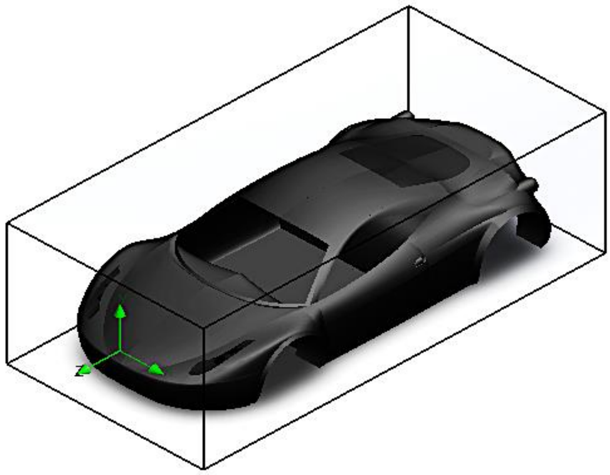


Fig. 3. Computational domain for the photogrammetric car model

Accordingly, the workflow of this study is presented in Figure 4. The research's methodology began with the used of photogrammetry technique for the following computational CFD model.

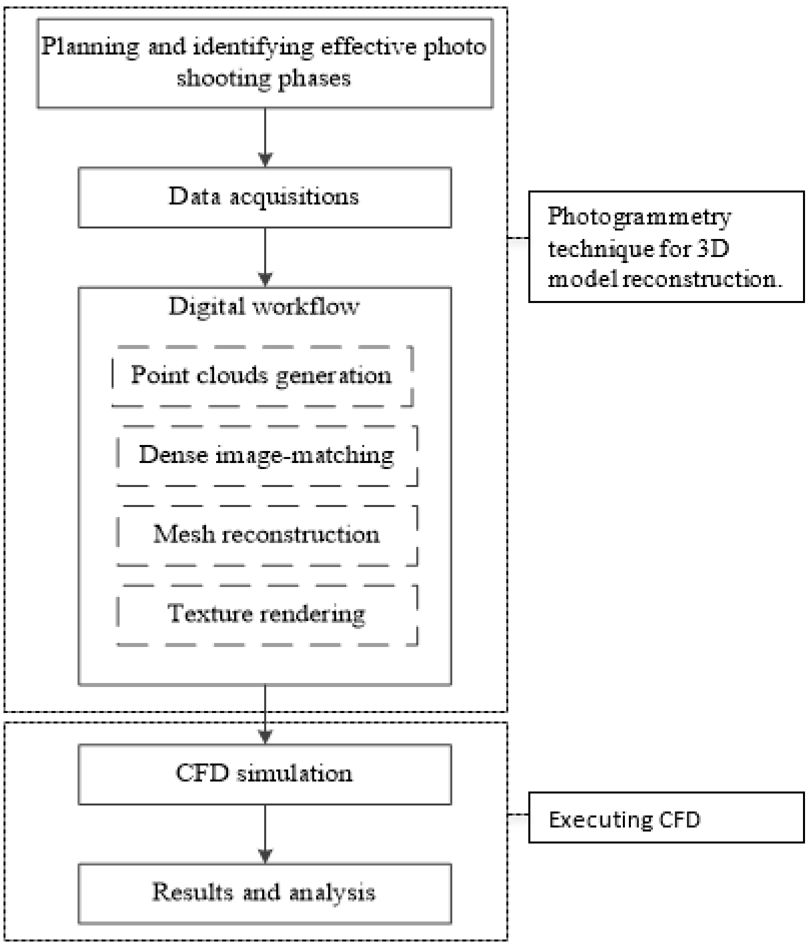


Fig. 4. The overall methodology for the research investigation

3. Results and Discussions

3.1 Pressure Flow Visualization

Figure 5 portrays the pressure distribution across 3D car model. The simulation displays that the pressure remains low when it passes from the front to the top and back of the model as presented by the blue contour. Moreover, at the inclined front and rear windscreen of the 3D car model, there are increased in pressure around these regions that are presented by red-yellow contour [22]. This is due to the sudden angle differences between the hood and A-pillar (front), boot and C-pillar (rear) respectively.

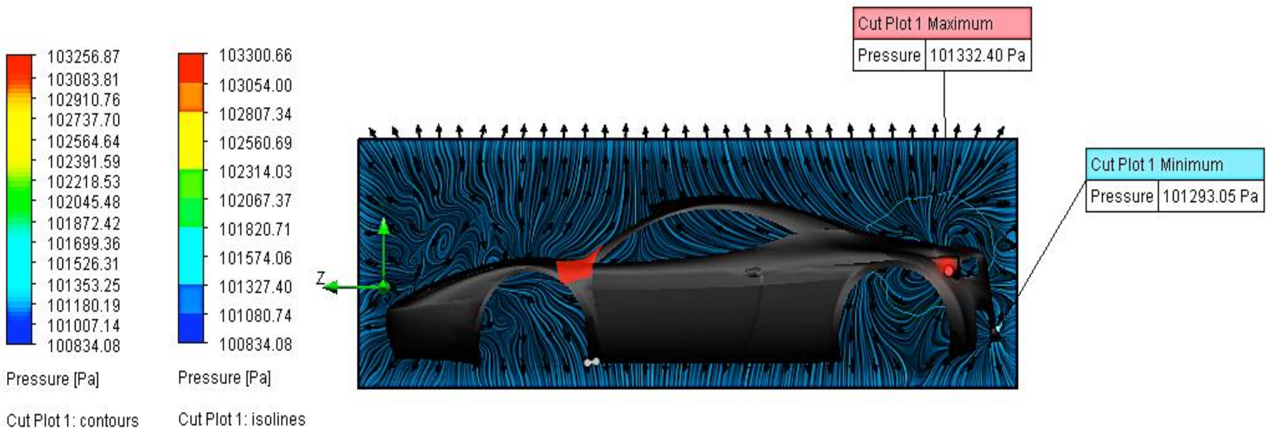


Fig. 5. Pressure contours and isolines across the photogrammetric car model

Figure 6 shows the surface plot contour of the pressure magnitudes subjected on the CAD model surfaces respectively. Primarily, the model is set at the standard atmospheric pressure (101325 Pa) and therefore, the car model body is subjected on equal pressure. However, this is not the case for the taillights as the pressure ranges of 101800 to 102400 Pa displayed by the green contour. The pressure flow in these regions increases because it approaches narrower gaps between the taillights and the back fenders [22, 23].

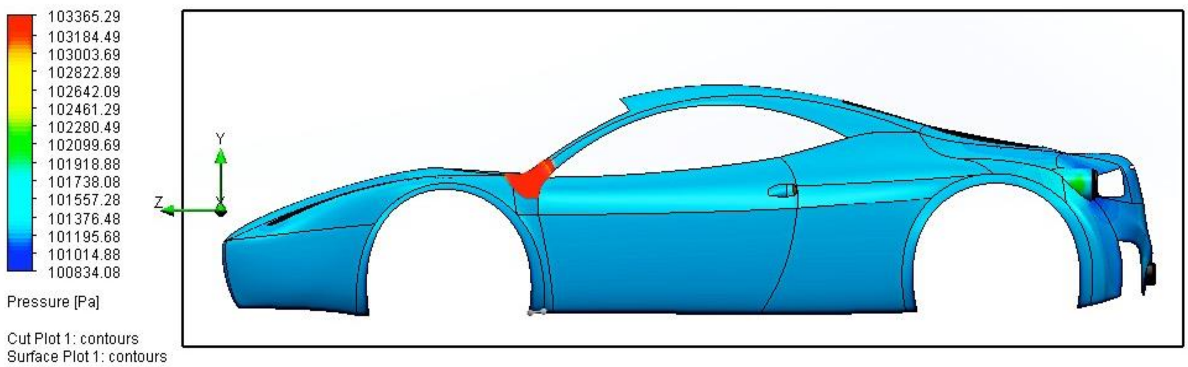
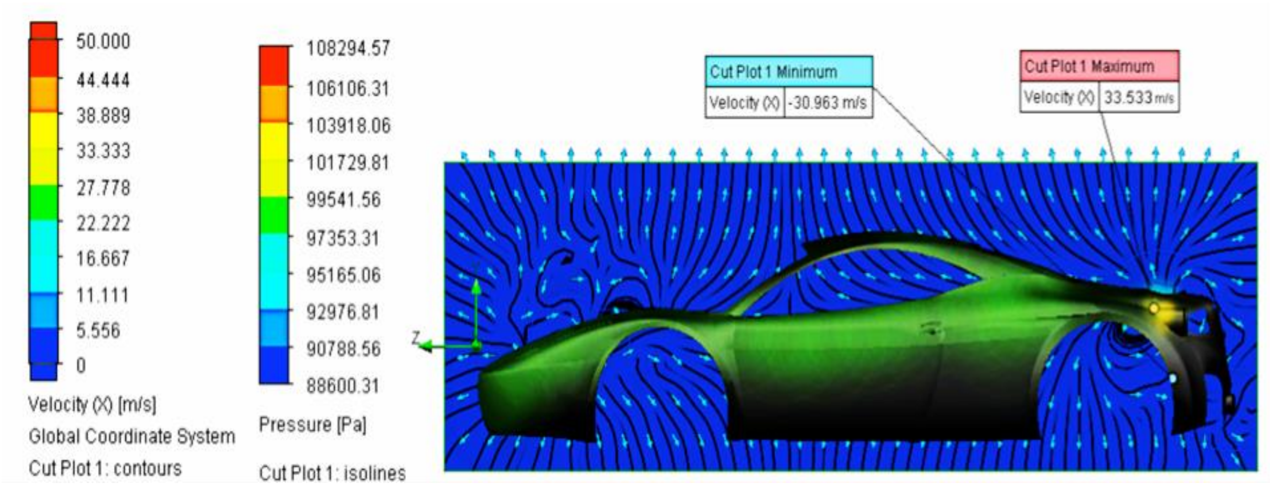


Fig. 6. Pressure distribution over the surfaces of car model

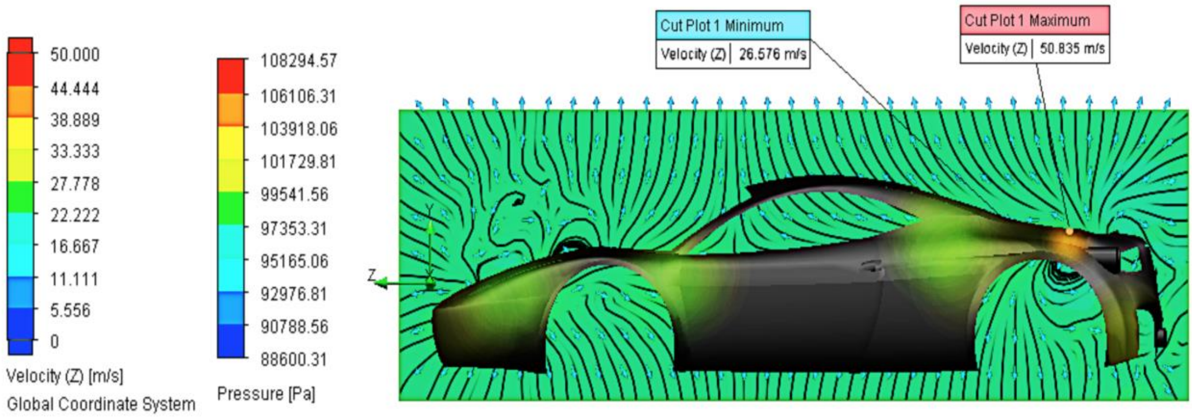
3.2 Velocity Flow Visualization

Figure 7(a) and Figure 7(b) show the contour of the velocity flow magnitude for the 3D car model in the X and Y planes respectively. In Figure 7(a) of the X-cross section, the velocity magnitude at the front region of the CAD model is low, where it ranges up to about 5.6 m/s as indicated by the blue contour. The highest velocity flow magnitude is created at the hood of the car as it turns into a free stream far from the model. Additionally, as the flows rise along the front side members of the model the velocity flows increases of approximately 33 m/s that is shown by the red-yellow contour. Thus, this could be the result of the developed stagnation point in that region [24].

In Figure 7(b) of the Z-cross-section, similar observations on the velocity flows can be seen as in Figure 7(a). However, low velocity is developed at the downstream of the C-pillar (rear) of the model in which a turbulence structure is formed in the wake region.



(a)

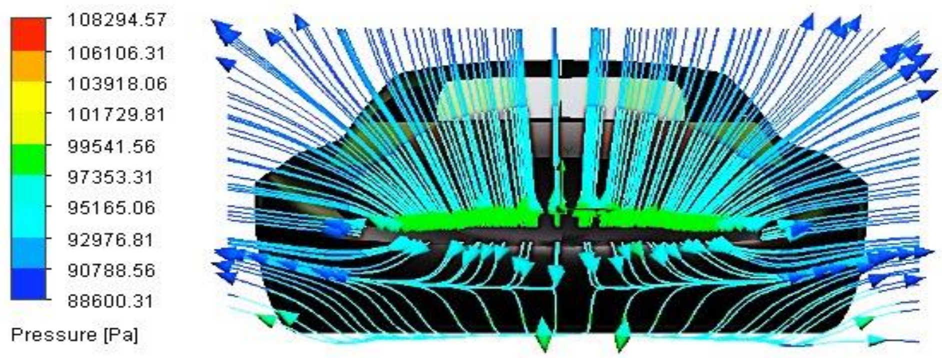


(b)

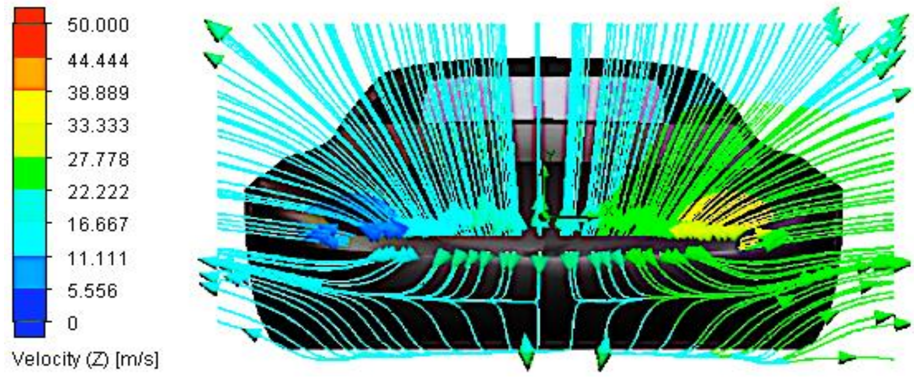
Fig. 7. Velocity contours and isolines across the photogrammetric car model on different transverse cross-sectionals: (a) X-planes (b) Z-planes

3.2 Flow Trajectories

The flow trajectories are simulated using the average magnitudes. Figure 8 portrays the airflows at the A-pillar (front) of the photogrammetric car model that are separated at both the top and bottom regions respectively. This flow separation phenomenon has occurred due to the aerodynamic shape of the car model [22, 25]. Thus, the arrows and lines trajectories represent the pressure and velocity differentials in the respective figures.



(a)



(b)

Fig. 8. Airflow trajectories across the photogrammetric car model: (a) pressure distribution and (b) velocity distribution

Consequently, as the airflows travel across the pillars of the car model they may take the forms of vortices or eddies as shown in Figure 9. Thus, a maximum vorticity is observed at the back of the car. This is due to the formation of free shear layer that leaves the edges of the car model and roll-ups causing a chaotic motion of lower vortices [26]. Moreover, a spanwise vortex is formed at the A-pillar (front) junction of the model, where the local spinning motion is at its minimum magnitude. In addition, Figure 10 shows the velocity trajectories in the X and Z planes with the velocity flow, which is between of 0 to 50 m/s.

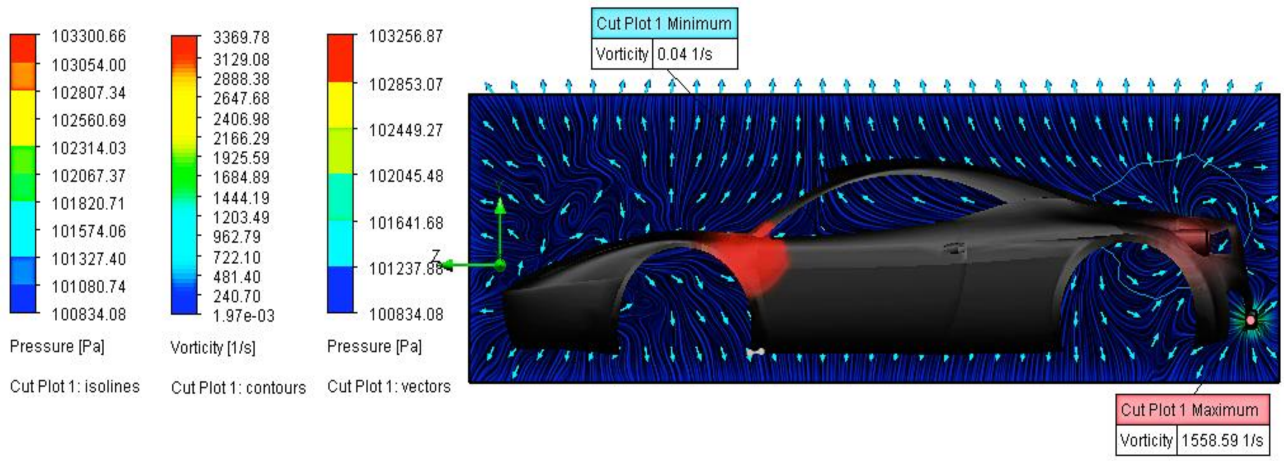


Fig. 9. Vortices formation across the photogrammetric car model

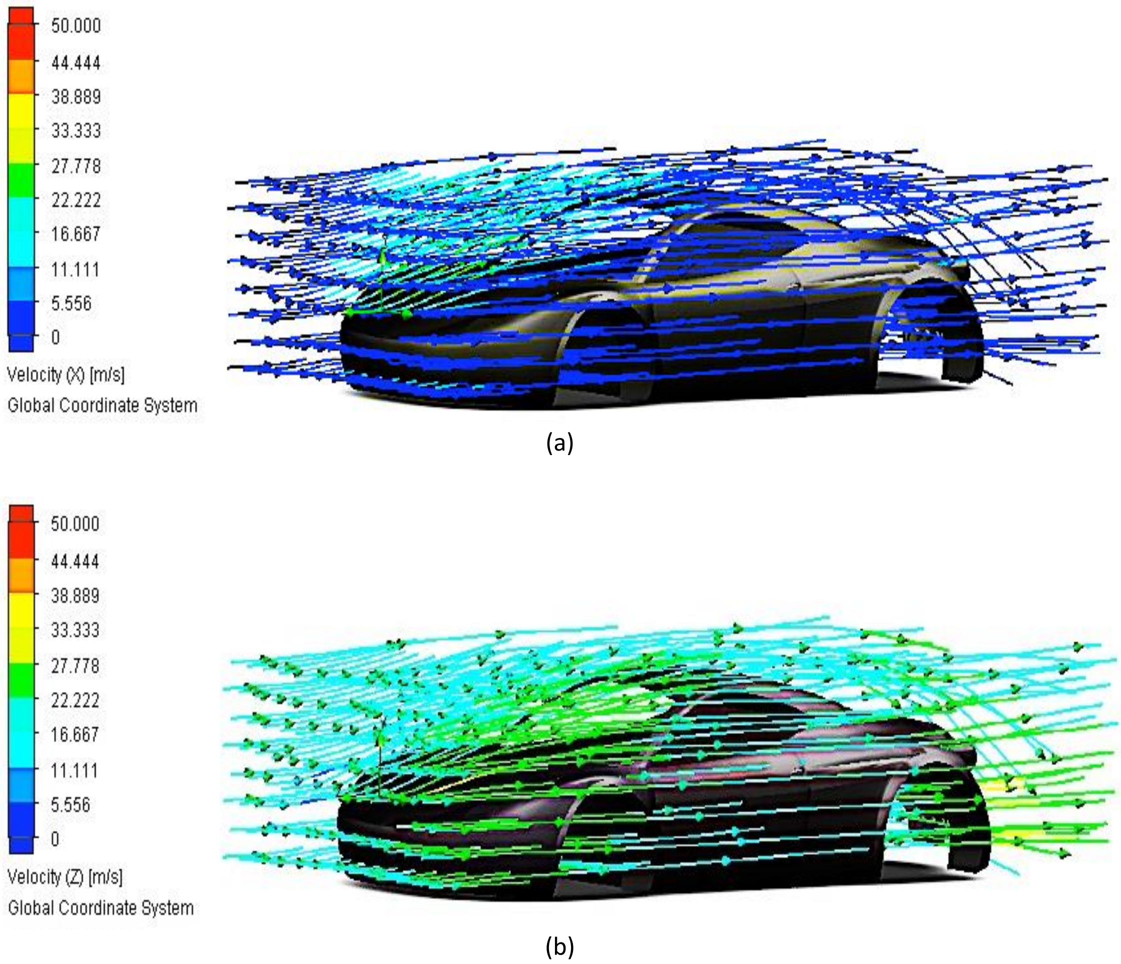


Fig. 10. Trajectories patterns across the photogrammetric car model on different transverse cross-sectionals: (a) X-plane (b) Z-plane

3.3 Photogrammetry Methods in CFD Studies

In this study, the photogrammetry method is used to produce a mesh model for the subsequent Computational Fluid Dynamics (CFD) studies. In general, a computational model of the targeted object or part is the prerequisite to carry out every CFD simulation analysis. Unquestionably, the first difficulty will arise in the very beginning of the CFD study is the development of the 3D geometric body of a specific object or part. Moreover, complex features and shapes can be very challenging and hard to create using CAD drawing, for instance, SolidWorks in certain case studies. That is, the features such as sharp edges with multiple gaps and patterns in between, blended chamfers, complex curve generation, composite curve and others can consume a lot of time to draw completely in the CAD platforms. As a result, this can lead to additional expenditure by hiring professionals to come up with the whole completed drawing and 3D model of the targeted object or part, which directly consumes time as well.

Therefore, the photogrammetry method is very useful in many ways. The technique does not only extract the surface information precisely but also generate an accurate 3D model instantly. Furthermore, the method is used in this study because it is more convenient to move the camera around the object compared than using 3D scanning equipment instead. Besides, the method offers shorter digitizing period with excellence results. As mentioned previously, the photogrammetric data acquisition works with image recognitions to develop photogrammetric 3D model in the Autodesk ReCap. This reconstructed 3D model is then imported into the SolidWorks software to be used as a computational model for the following CFD analysis in this study. As a consequence, the post-processing results shown by the analyses are very reliable and concise. Also, the simulations illustrated by the computational car model (photogrammetric model) in this study are satisfactory and the fundamentals of CFD studies are largely intact. Hence, the photogrammetry methods can be applied readily to aid and solve various CFD investigations without having to use expensive and complex equipment for the initial 3D model generation. Most importantly, the integration of the photogrammetry techniques with CFD studies does not only provide potential cost and time solution but also a whole new level of insights into dynamic thermo-fluid studies especially in the automotive field.

4. Conclusions

The used of photogrammetry technique in the beginning of this study is to develop a precise 3D model of the targeted sedan car demonstrator. Thereafter, the reconstructed 3D model in used as a computational model to carry out the subsequent CFD simulations. Indeed, the used of photogrammetry technique in the CFD investigation of airflow distribution has greatly reduced the expenses and time to prepare any geometric and complex shape models for simulation. Also, the analyses of the airflow studies over the computational model have consistently shown excellence results. As a consequence, the post-processing results shown by the analyses are very reliable and concise. Also, the simulations illustrated by the computational car model (photogrammetric model) in this study are satisfactory and the fundamentals of CFD studies are largely intact. Therefore, it can be concluded that the CFD calculation schemes have demonstrated the prediction of flow fields and recirculating zones such as vortices over the photogrammetric car model. This is because the basic concepts of the flow models are feasible to show a strong relation to the geometry structure of the reconstructed 3D model using the photogrammetry method.

In future, creating higher quality photogrammetric models can enhance the accuracy of the fluid flow investigations. This can be achieved by optimizing the developed meshes in the photogrammetry software to reduce the calculation errors in the CFD analysis. Further, the photogrammetric conditions have to be studied as this can aid in the context of producing better CFD results.

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