GIET UNIVERSITY JOURNAL, Engineering, Science, Agriculture & Management 2024, SPECIAL ISSUE **"Sustainable Engineering, Technology and Management (NSETM-2024)"**

PP. – 50-59, Manuscript Received: 20th March 2024; Revised 28th June2024, Accepted: 30th July, 2024

DrivAer Car Aerodynamics with 3D Experience: A Comparative Study

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Abstract: A study has been conducted to assess and compare the aerodynamic parameters of the DrivAer car, using the 3D Experience Platform SIMULIA. Aerodynamics is a crucial factor in determining the performance and efficiency of vehicles, especially in terms of drag reduction and stability enhancement. By analyzing computational simulations, this paper evaluates the impact of various design configurations of DrivAer car on essential aerodynamic parameters like drag coefficient, lift coefficient, and flow patterns. The use of the 3D Experience SIMULIA provides a comprehensive and efficient platform for conducting detailed assessments, enabling engineers to explore various design iterations. The results of this study will be beneficial in optimizing the aerodynamic performance of the DrivAer car, leading to an overall improvement in its efficiency and the effectiveness of computational simulation strategies.

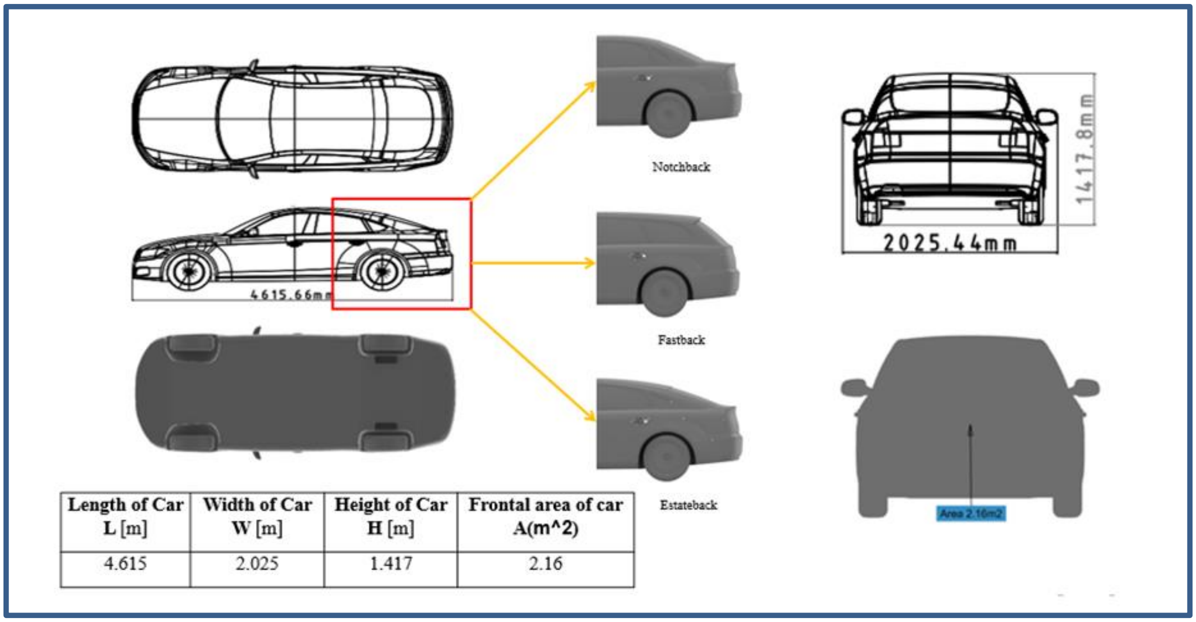
***Keywords*— Aerodynamics, DrivAer Car, 3D Experience, Computational Simulation, Drag Coefficient, Lift Coefficient, Flow Patterns.**

1. Introduction:

The study of aerodynamics in automobiles is a pivotal aspect of automotive engineering, focusing on how air interacts with moving vehicles. This field is crucial for enhancing vehicle performance, including fuel efficiency, safety, stability, and handling. Aerodynamics involves the analysis and design of vehicles to minimize air resistance or drag, which affects a vehicle's acceleration, top speed, and fuel consumption. The shift towards computational methods over traditional wind tunnel testing has expedited the aerodynamic analysis, making it more cost-effective and time-efficient [1]. Recent advancements have seen automotive companies experimenting with new designs and devices to enhance the aerodynamic properties of vehicles, leading to models with significantly reduced drag coefficients [2]. The evolution of aerodynamic study has led to the incorporation of sophisticated computational fluid dynamics (CFD) and machine learning algorithms to predict and optimize the aerodynamic performance of vehicles, as demonstrated by Xingchuan Ma's research on car shapes and their impact on aerodynamics [3]. The application of aerodynamics extends beyond conventional vehicles to racing cars, where it plays a significant role in improving speed and performance through the design of car shapes, rear fenders, and DRS systems [4]. Researchers and developers often use generic models such as Ahmed body [5] and MIRA model [6] to understand and describe the aerodynamic flow features, keeping in view the shape constraints. DrivAer model is a modular concept based on the geometries of the Audi A4 and BMW 3 Series, offering interchangeable rear-end forms and underbody geometries [18]. It has been extensively studied through wind tunnel experiments and numerical simulations to analyze its aerodynamic performance, focusing on drag and lift coefficients [8]. Experimental data includes force measurements using a virtual center balance and detailed CAD geometry for validation of numerical methods [7][9] [10] [11] [12]. Additionally, simulations using structured finite difference overset grids have provided insights into the aerodynamic behavior of the DrivAer model, comparing results with experimental and numerical data from previous studies [15]. Thus, the DrivAer model is a valuable tool for investigating and improving the aerodynamic characteristics of modern vehicles. Efforts have been made to extend the DrivAer model's applicability to high-performance car configurations, providing valuable insights for motorsport and academic research purposes [16]. The present paper assesses the impact of different design configurations of the DrivAer car on critical aerodynamic parameters such as drag coefficient, lift coefficient, and flow patterns. The study utilized the 3D Experience SIMULIA software, resulting in an overall improvement in the efficiency and effectiveness of computational simulation strategies.

2. Geometry Specification:

The present geometrical dimensions with DrivAer car rear end form, smooth underbody including mirrors, and wheels configuration have been taken for analysis. The acronym F_S_wM_wW_woGS describes the fastback vehicle with a smooth underbody, mirrors, and wheels without ground simulation. DrivAer fastback car dimensions are length L=4.6m, width W=1.81m, and height H=1.41m respectively shown in Figure 1.



Length of Car L [m]	Width of Car W [m]	Height of Car H [m]	Frontal area of car A(m^2)
4.615	2.025	1.417	2.16

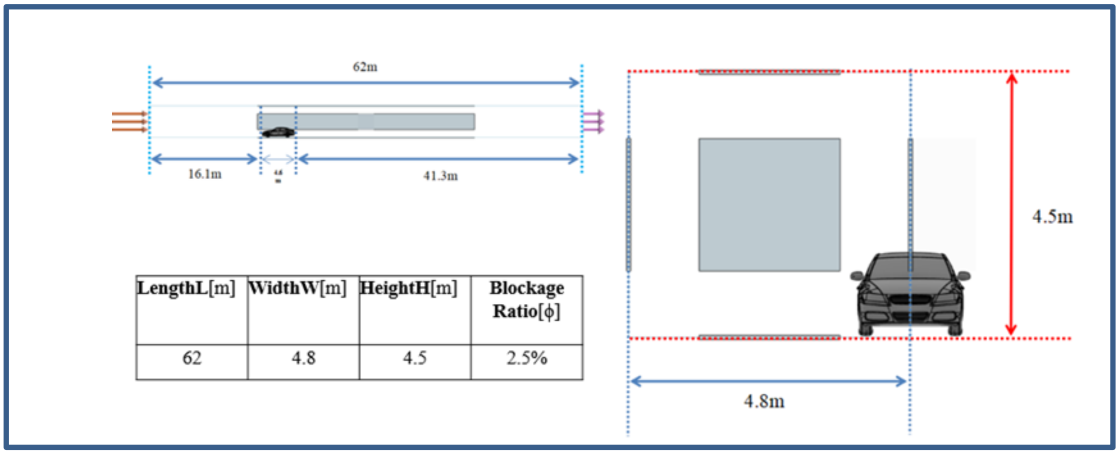
Figure 1: Dimensional Specifications for DrivAer Model

The full-scale CAD model has been imported for the present analysis which is available in the research community group TUM[18]. Figure 2 represents the isometric view of the imported CAD Model of DrivAer Fastback Car.

Figure 2: CAD Isometric model of DrivAer Fastback Car

3. **Computational Domain:** For the present analysis, the computational domain has been assumed by the original work Heft [7]. To allow a sufficient development of the turbulent flow characteristics, the DrivAer Fastback model has been placed at 2L from the domain inlet. The total length of the domain was chosen as 62m to ensure that the outflow conditions do not affect the near-body wake. Also, the computational domain has a total height of 4.5m and a half width of 48m. This equals a blockage ratio of approximately 2.5%, which is distinctly

smaller than the blockage ratio during the experiments. Furthermore, turbulence intensities at the inlet are chosen corresponding to the experimental values. Figure 3 shows the computational domain used in the present case.



LengthL[m]	WidthW[m]	HeightH[m]	Blockage Ratio[ϕ]
62	4.8	4.5	2.5%

Figure 3: Computational Domain use for F_S_wM_wW_woGS Setup

4. Meshing:

At this particular stage of the process, the computational grid is precisely developed through the utilization of the advanced 3D Experience Simulia Hex-dominant setup. This configuration is specifically designed to offer a seamless single-window workflow, thereby significantly enhancing the efficiency of the meshing process by swiftly generating mesh structures across the entirety of the geometric surface, as visually depicted in figure4. It is important to note that an impressive total of approximately 3 million individual meshes, known as control volumes, have been precisely created surrounding the entire computational domain for further analysis and simulation.

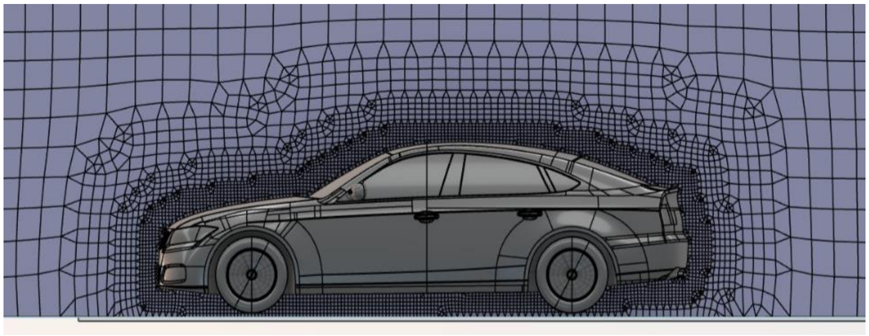


Figure 4. Mesh Generation around the F_S_wM_wW_woGS

5. **Grid Independent Test:** In this step, the grid independence study has been carried out for the generated volume elements [14]. Table 1., the parameter used for the present analysis. This ensures appropriate capture in volume cells around the surfaces of the car body. A comparison between the overall elements generated in the different grid systems with the coefficient of drag values. Table 2 represents the grid-independent study to ensure the exactness of the mesh results.

Table 1: Parameters use in Meshing Setup

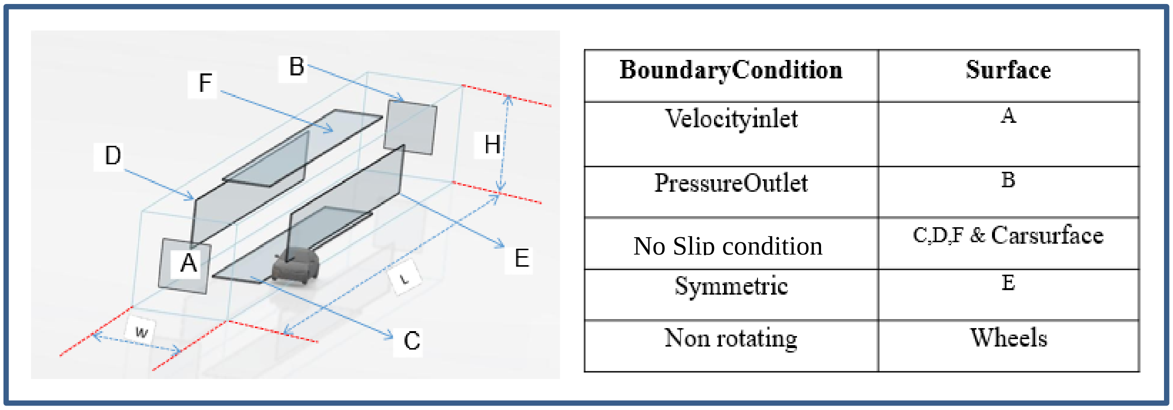
Sl. No.	**Factor**	**Parameters**
1.	Mesh max size	160mm, 120mm, 100mm
2.	Volume Mesh Target skewness	0.94
3.	Surface Mesh Target skewness	0.8
4.	First cell height in boundary layer	10mm, 20mm, 25.4mm
5.	Number of Boundary layer	4
6.	Growth Rate	1.3

Table 2: Validation of Drag Coefficient Values obtained with Different Mesh Elements for F_S_wM_wW_woGS

Sl no.	**Mesh No**	**No. of Elements**	**Mesh Element Size**	C_D
1.	Mesh 1	2365704	160 mm	0.3313
2.	Mesh 2	2994567	120mm	0.2353
3.	Mesh 3	3197053	100mm	0.2341

It can be observed that the drag coefficient values obtained with the mesh of 3M provide a good attainment at the same level of accuracy and hence validate the simulation procedure to be precise.

6. **Solver Settings:** Before beginning the numerical analysis of car exterior flow, it is necessary to finish the solver settings [17]. The solver configuration dialog box allows you to specify the solver type (3D), the viscous model, boundary conditions, and solution controls as shown in figure 5. The term "velocity-inlet" was used to refer to the wind tunnel's inlet face, while "pressure-outlet" was used to refer to the wind tunnel's outlet face. The velocity of the simulation takes as 8.3,15.27,23.61 m/s respectively.



BoundaryCondition	Surface
Velocityinlet	A
PressureOutlet	B
No Slip condition	C,D,F & Carsurface
Symmetric	E
Non rotating	Wheels

Figure 5: Boundary condition setup for F_S_wM_wW_woGS

7. Results Analysis

i. Drag Coefficient (Cd) and Lift Coefficient (Cl)

The drag coefficient for the F_S_wM_wW_woGS car model was calculated with the following formula is given in the equation no 1 and 2 respectively.

$$C_D = \frac{F_D}{\frac{1}{2}\rho U^2 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$C_l = \frac{F_l}{\frac{1}{2}\rho U^2 A} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where:

F_D: total force which consists of the pressure and friction force in the x-direction (N).
F_L: Total Lift force in the y-direction(N)
ρ: fluid density (kg/m3)
U: fluid velocity (m/s)
A: reference area (m2)

The drag coefficients derived from the simulation were meticulously calculated and subsequently compared with the empirical findings, as illustrated in the tabular representation provided below for comprehensive examination and analysis.

Table3. Drag and Lift coefficients comparison in F_S_wM_wW_woGS at different velocities

Sl. No.	F_S_wM_wW_woGS	Drag Force(N)	Lift Force(N)	Drag coefficient (C_D)	Lift Coefficient (C_L)	Experimental (C_D)
1.	**Velocity 8.3m/s**	**29.7**	**8.38**	**0.4**	**0.093**	**0.275**
2.	**Velocity 15.27m/s**	**86.12**	**36.16**	**0.342**	**0.119**	
3.	**Velocity 23.61m/s**	**207.6**	**61.81**	**0.345**	**0.085**	

From the table3. drag and lift coefficient values has been obtained that shows a relative error of 20.2% has been achieved for the overall drag coefficient at the highest velocity 23.61m/s compared to that of existing experimental results.

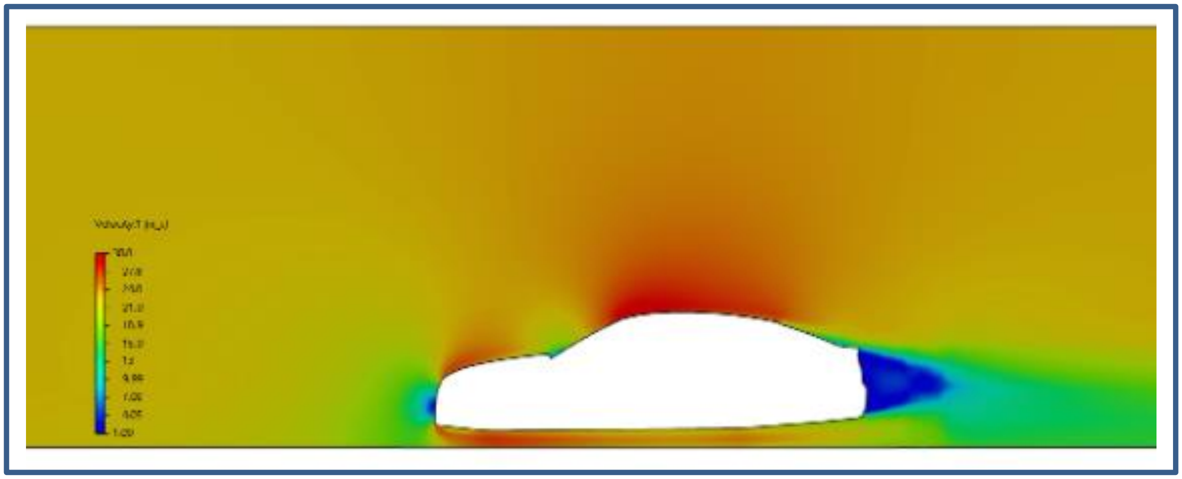


Figure 6: Velocity Contor Plot around the F_S_wM_wW_woGS

From the velocity contour plots at the symmetry plane in figure 9, a recirculation zone is seen just after the detachment of the rear end. This gives an insight view how the drag force influences on the F_S_wM_wW_woGS. A similar approach is also seen by Asthon et.al [13].

ii. Pressure Coefficient (Cp)

To determine the pressure coefficient, it is necessary to extract the pressure data from both the upper and lower regions of the car surface, specifically along a central line aligned with the x-axis of the vehicle. This extraction process can be effectively carried out by leveraging the functionality of the Moments tool integrated into the Simulia application. Subsequently, utilizing the pressure values acquired from the aforementioned step, the pressure coefficient can be accurately computed by applying the mathematical expression presented in equation 3 as outlined below:

$$C_p = \frac{p - p_\infty}{\frac{1}{2}\rho U^2} \quad \ldots\ldots\ldots\ldots\ldots\ (3)$$

where:

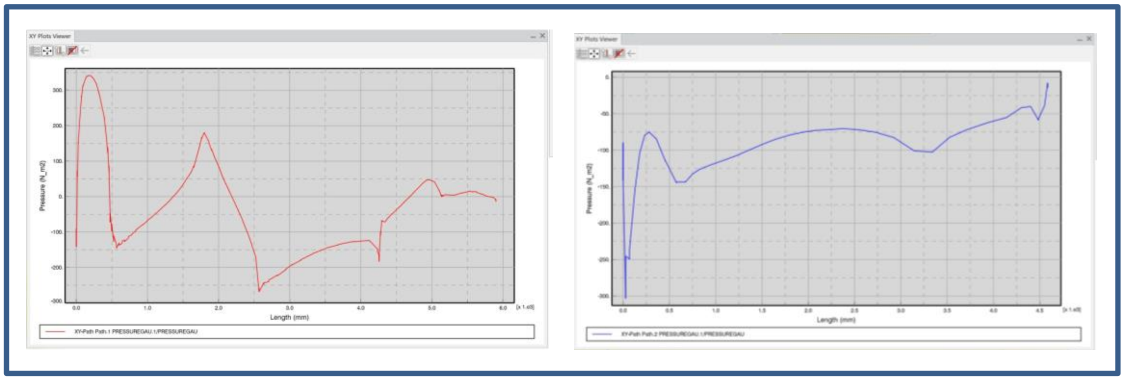
p: static pressure at the point of calculation (Pa)

p_∞: static pressure in the freestream (Pa)

ρ: freestream fluid density (kg/m3)

U: freestream fluid velocity (m/s)

From the Pressure coefficient plots for the upper and below as shown in figure 7a and 7b, the F_S_wM_wW_woGS , shows the pressure gets high in the front i.e. stagnation zone, at the windshield, rear end trunk, and the front wheels.



a. b.

Figure 7: a. Pressure coefficient plot over the F_S_wM_wW_woGS

b. Pressure coefficient plot under the F_S_wM_wW_woGS

8. Conclusion

i. A simulation has been conducted to predict the aerodynamic performance of a static 3D DrivAer (F_S_wM_wW_woGS) in the 3D Experience Simulia Application.

ii. The results achieved show a relative error of 20.2% for the overall drag coefficient at the highest velocity of 23.61m/s compared to that of existing experimental results.

iii. The Simulia CFD App has been able to predict the drag & lift coefficients, wake flow patterns alone with the pressure coefficient over and below for the DrivAer F_S_wM_wW_woGS Car, bringing insights and design strategies for improving its efficiency.

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