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CFD-based optimization of truck fairing structure

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Abstract. Computational Fluid Dynamics (CFD) technology was used to analyse a big truck with newly-designed head. Three models were designed to analyze: (1) Project 1: a trunk without fairing, (2) Project 2: a trunk with an old fairing, (3) Project 3: a trunk with a new fairing (the old fairing of Project 2 is particularly moved 500mm forehead). During the movement of vehicle, the more similar streamlined shape of the vehicle is, the more reduction of the wind resistance can achieve. The wind resistance could be thereby reduced in case of a truck having a fairing because of a more similar with streamlined shape for the truck structure. The challenge here is that the exactly optimal location of the fairing on the vehicle is not clear and generally was determined only by experience. However, here by the comparison of each model with CFD analysis, engineers can give the better design for the goal of reducing the resistance fuel consumption.

1. Introduction

The structure of vehicles directly affects fuel consumption. The body shape of the vehicles have to conform to streamlines shape as far as possible when considering the gas dynamic aspects e.g. wind resistance and safety coefficient demand. Drag coefficient, which refers to the wind resistance, exhibits real close relationship with the stability and safety of vehicles [1]. Generally, the wind resistance mainly comes from the front of the vehicle when it is on running. In this case, drag coefficient plays a key role on vehicle performance, whereby as reported that 60% of the fuel consumption is assumed to overcome the wind resistance when a car is running at the speed of 80 km/h [1-6].

In this paper, the professional Computational Fluid Dynamics (CFD) software named SolidWorks Flow Simulation was used to analyze a big truck with newly-designed long-headstocks. Three models were designed here: 1) Project 1, a truck without fairing; 2) Project 2, a truck with an old fairing, 3) Project 3: a truck with a new fairing (the old fairing is particularly moved 500mm forehead compared with Project 2). The smaller wind resistance is achieved during the movement of vehicle if its whole structure is more similar with the streamlined shape. In this context, the wind resistance could be reduced in case of a truck having a fairing because of in such way the truck structure being more similar with streamlined shape. It is difficult to fix the fairing the fairing on the vehicle at exactly optimal location and generally was determined only by experience. However, here by the comparison of three different designs with CFD analysis, the optimal location of the fairing could be fixed for the goal of reducing the resistance fuel consumption.



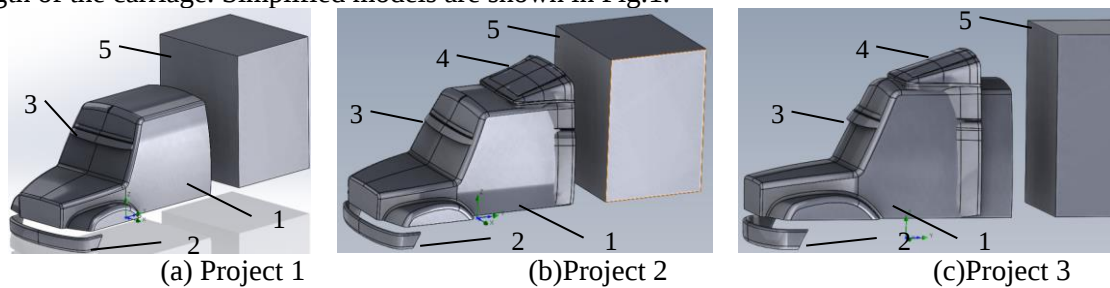
2. Premise & Simplification

2.1 Premise of simulation

This numerical simulation is based on the CFD turbulence model in an open state. The analysis object is the air fluent around the trunk inside the computational domain. To simplify the project, a standard κ - ε double equation model is chosen since the fluid is only air. Addition assumptions are as follows: (1) physical parameters between solid and fluent are set as constants; (2) fluent is set as turbulence; (3) carriage of the trunk is truncated to reduce the computational domain size and grid number; (4) ignore the influence of the fluent temperature [2-3, 7-12].

2.2 Simplified model

The exact model of trunk is very complicated. To accelerate the convergence rate and reduce processing workload, the model of the trunk should be simplified. Simplifications are as follows: 1. to remove small fillets and make sharp corners smooth; 2. to integrate the head as a whole; 3. To cut the length of the carriage. Simplified models are shown in Fig.1.



1-Cab; 2-Front-bumper; 3-Sun shield; 4-Fairing; 5-Carriage;
Notes: 1-4 is called head as a whole, 5 is just named carriage.

Fig.1 Simplified Model of Truck Body

3. Pre-treatment

3.1. Definition of Drag coefficient & Boundary conditions setting

Definition of Drag coefficient is: $C_t = 2F_t / \rho U^2 S$, which is the resistance acting on the entity along the direction of the wind, S is the frontal projected area of the entity, ρ is air density, U is the relative velocity of truck to air.

In the SolidWorks Flow Simulation, the air is considered to be incompressible gas. Pressure-based coupled solver and implicit iterative method are chosen. The κ - ε model and first-order discrete form are chosen. Pressure and velocity coupling algorithms are selected to be the SIMPLE algorithm.

Note: The κ - ε model has become the most popular of the turbulence models and is often used in many calculations of flow of practical interest.

Boundary conditions settings are as follows:

Inlet: velocity is 30m/s (the trunk is at around the speed of 100km/h)[13-14];

Outlet: pressure-outlet[8,15-16].

3.2 Mesh & Solve

Since the models are complicated, the option of 'Narrow channel' is used to refine the mesh. With the same setting, total grids of all the projects are close to 5 million. Details can be found at Table 1. A high configuration fluid analysis workstation is used for calculation (8 core processor +16G memory, solid state hard disk and professional graphics card)[17].

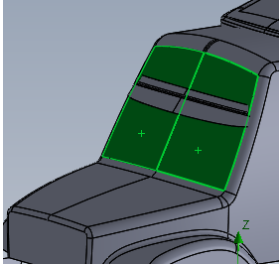
Table 1 Calculations

Project name	Project 1 (without Fairing)	Project 2 (Fairing I)	Project 3 (Fairing I 500mm forward)
Total grids	4764505	4993732	4966173

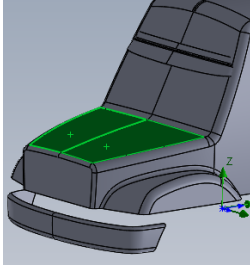
Fluent grids	1926675	2147930	2135526
Solid grids	1422271	1317488	1311244
Partial grids	1415559	1528314	1519403
CPU time/s	130443	41847	44844
Iterations	1494	454	485

Table 2 Pressure Distribution

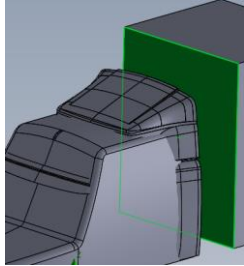
Project names	Project 1	Project 2	Project 3	Project 1-Project2	Project 1-Project 3
Glass window/Pa	101843.50	101785.09	101768.05	17.04	75.45
Area/m2	2.2021	2.2021	2.2021	-	-
Hood/Pa	101399.10	101562.57	101557.04	5.53	-157.94
Area/m2	2.0270	2.0270	2.0270	-	-
Carriage front face /Pa	101485.08	101404.37	101389.76	14.61	95.32
Area/m2	6.4400	6.4400	6.4400	-	-
Total Pressure/Pa	304727.7	304752	304714.9	12.83	37.18



Glass window



Hood

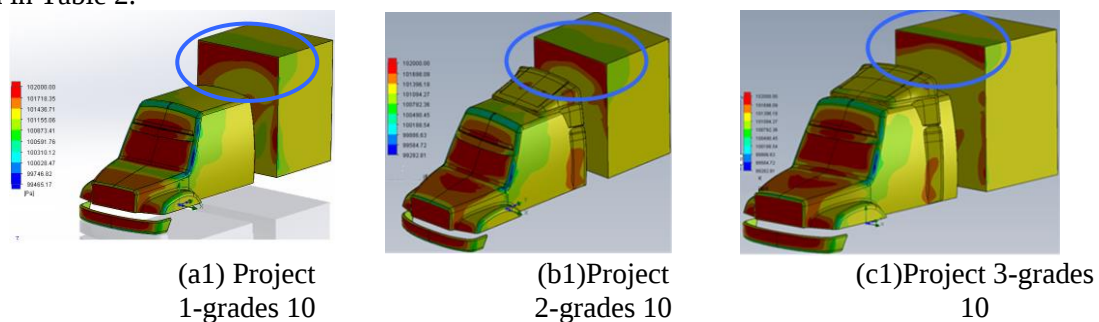


Carriage front face

4. Results

4.1 Surface Pressure Contours

Fig.2 refers to the pressure contours of the three projects. (a1) & (a2), (b1) & (b2), (c1) & (c2) are almost the same, only with different color grades. (a1)-(c1) with 10 color grades, while (a2)-(c2) with 100 color grades. Note: high color grade means smooth color change but could hardly be provided insights into the design, while low color grade means poor color change but could easily be provided insights into the design. Compared with the 3 projects, judging from the entire trunk color (especially the circular area), Project 3 has the least red range (high pressure) indicating that this fairing is good for reducing the pressure on carriage. The pressure distribution (including glass window, hood and carriage front face) is listed in Table 2.



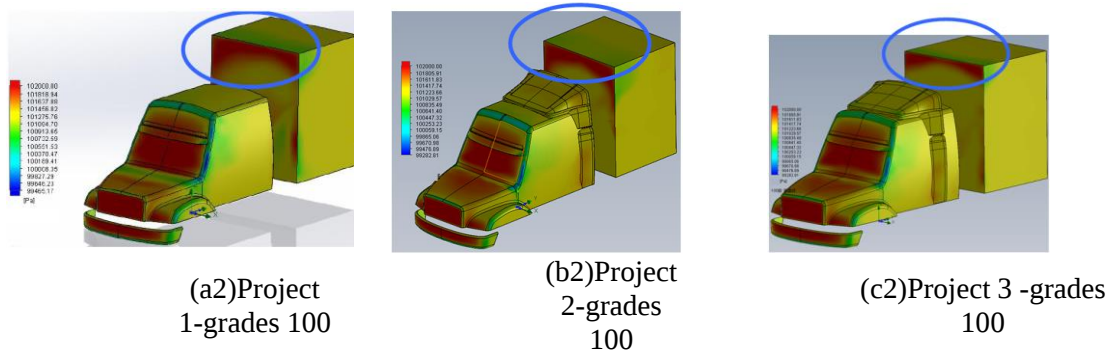
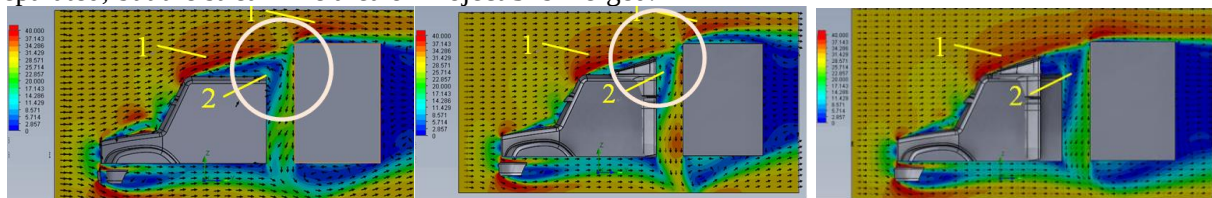


Fig.2 Pressure contours of Truck Body

As shown in Table 2, the pressure of the glass window, hood and carriage face from big to small are: Project 1> Project 2> Project 3. Commonly speaking, the glass window is the weakest part. With the help of fairing, the pressure of the glass window is decreased by 75.45 Pa comparing Project 3 to Project 1, and by 17.04 Pa comparing Project 2 to Project 1. The pressure of hood is decreased by 5.53Pa compared Project 2 to Project 1, but increased by 157.94 Pa compared Project 3 to Project 1, which illustrated that the fairing separated the wind pressure from glass window to other parts, so that to release the pressure of the vulnerable glass window. The pressure of carriage front face is also reduced by fairing.

4.2 Velocity contours (extract the middle section)

Fig.3 refers to the velocity contours of the three projects (extract the middle section). Comparing with the 3 projects, we can observe that the streamline area between head and carriage of Project 1& 2 are separated, but the streamline area of Project 3 is merged.



(a) Project 1-grades 10

(b)Project 2-grades 10

(c)Project 3-grades 10

1-High velocity zone; 2-Low velocity zone;

Notes: the circular area of (a) (b) is separated area the circular area of c) is merged.

Fig.3 Velocity contours of Truck Body middle section

Judging from color of contours, blue means low velocity zone, while red means high velocity zone. The separated area is name for the area that the velocity changed rapidly.

As shown in Fig. 3, in Project 1, without the fairing, the separated area could be clearly observed above the trunk; in Project 2, since the fairing is not completely occupied the separated area, so the design do not conform to the streamline; in Project 3, the fairing almost completely covers the separated area, so that the design conforms to the streamline.

4.3 Trunk flow trajectories

Fig.4 shows the velocity 3D flow trajectories around Truck Body. In fact, 3D animation is also can be exported to display the motion state. However, the 3D trajectories temporarily have no direct information with value.

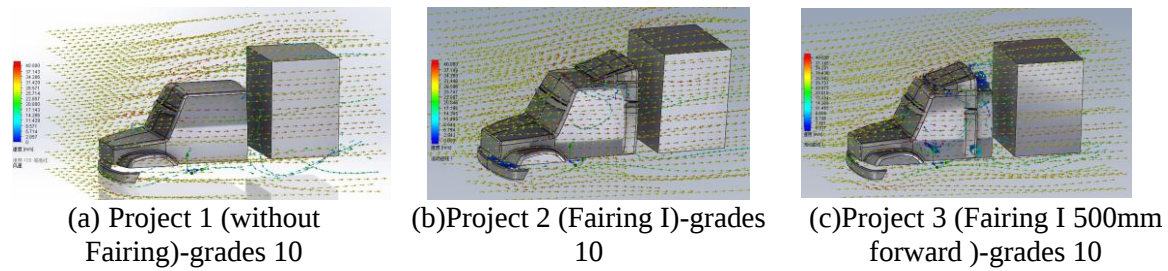


Fig.4 Flow trajectories around Truck Body

4.4 Drag Coefficient

Trunk in motion gets two kind of resistances: 1. Wind resistance coefficient (also named drag coefficient); 2. Wind resistance force. The definition of drag coefficient is shown in 2.1 [16-19].

After iterative calculation, Fig.5, Fig.6 and Table 3 are obtained. Fig.5 is the wind resistance coefficients of all the 3 projects. Fig.6 is the wind resistance forces of all the 3 projects. Combined with Fig.5 and Fig.6, we can see that the iterative curve of Project 1 fluctuated severely. The reason may be that the stable calculation of wind resistance force & coefficient are hard to obtain without fairing. On contrast, with the fairing, the calculations are relatively stable, according to curves of Project 2 & 3. The wind resistance forces of Project 1 (without Fairing), Project 2 (Fairing I) and Project 3 (Fairing I 500mm forward) are 2358N, 2111N and 1761N, respectively. Accordingly, the drag coefficients of 3 projects are 0.784, 0.689, and 0.571, respectively. The drag coefficient and wind resistance force of Project 3 are the smallest, so the structure of Project 3 is the best one among the 3 projects [6, 18-20].

Table 3 Wind resistance force & coefficient

Project names	Wind resistance force(N)	Drag coefficient
Project 1	2358.569	0.7836654
Project 2	2111.374	0.6894526
Project 3	1761.157	0.57082067

Note: in Table 3, the Wind resistance force & coefficient of Project 1 is the average between irritation 1000 and 1500. The wind resistance force & coefficient of Project 2 is the average between irritation 200 and 454. Because of good convergence, the curve of Project 3 has been descending before convergence, so the average is gotten from the last 5 irritations.

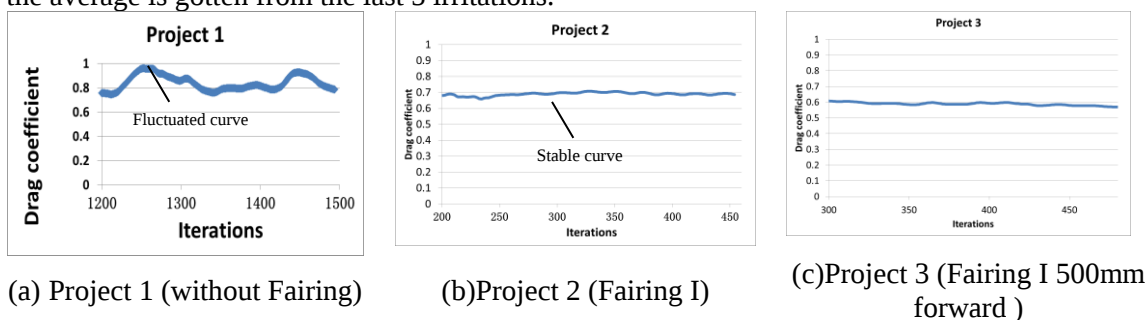


Fig.5 Contrast of Drag coefficient

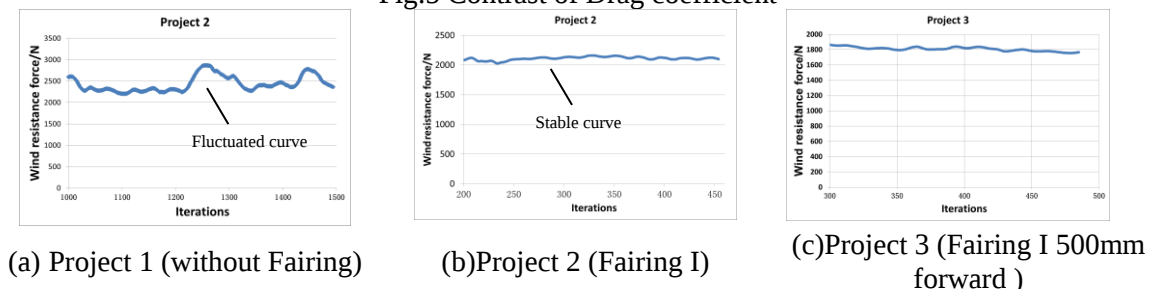


Fig.6 Contrast of wind resistance force

5. Conclusions

(1) The wind resistance forces of Project 1 (without Fairing), Project 2 (Fairing I), and Project 3 (Fairing I 500mm forward) are 2358N, 2111N, and 1761N, respectively. The drag coefficients of 3 projects are 0.784, 0.689, and 0.571, respectively.

(2) According to (1), the drag coefficient and wind resistance force of Project 3 are the smallest, so the structure of Project 3 is the best one among the 3 projects.

(3) The more similar streamlined shape of the vehicle can obtain the smaller wind resistance during the movement of vehicle. Therefore, the wind resistance could be reduced when a truck has a fairing because of the truck structure being more similar with streamlined shape. The challenge here is that the exactly optimal location of the fairing on the vehicle is not clear and generally was determined only by experience, which is not good. In this case, the optimal one could be fixed by the comparison of different design models with CFD analysis for the goal of reducing the resistance fuel consumption.

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