Porsche Engineering Services, Inc.

# 11 Aerodynamic Drag Assessment

*Computer Fluid Dynamics (CFD) analysis was used in the ULSAB-AVC Program to evaluate the aerodynamic concept from the very beginning of vehicle concepts .*

## 11.1 BACKGROUND

A vehicle's aerodynamic drag has a significant influence on its $CO_2$ emissions (fuel consumption). One of the necessary input parameters for a fuel consumption calculation is the total vehicle resistance, which is a function of the aerodynamic drag, rolling resistance, climbing resistance and acceleration resistance. For the calculation of the aerodynamic drag, the aerodynamic drag coefficient [$c_w$] is a necessary input parameter.

$$\text{Aerodynamic Drag} = \frac{\text{Air density x Frontal area x Aerodynamic Drag Coefficient x Velocity}^2}{2}$$

Optimization of the aerodynamic drag, which is normally done with wind tunnel testing in a full vehicle development program, was not foreseen in the ULSAB-AVC concept phase.

### 11.2. Aerodynamic Drag Benchmarking

In the ULSAB-AVC Program, benchmarking data of aerodynamic drag coefficients [$c_w$] were gathered to establish a $c_w$ range for the most current C-Class and PNGV/PNGV-Class vehicles.

### 11.2.1. Benchmarking C-Class Vehicles

Benchmarking data of aerodynamic drag coefficients for current C-Class vehicles were gathered through publicly available information (e.g. internet, OEM publications). The following C-Class vehicles were used for benchmarking.

- Ford Focus (2-door hatchback, 4-door sedan, 4-door wagon)
- VW Golf IV
- Opel Astra
- Opel Astra Eco 4
- Peugeot 307
- Audi A3
- Audi A2
- Audi A2 1.2 TDI
- Fiat Eco Basic (prototype)

The results as shown in Figure 11.2.1-1 display a range of aerodynamic drag coefficient from 0.25 to 0.36.

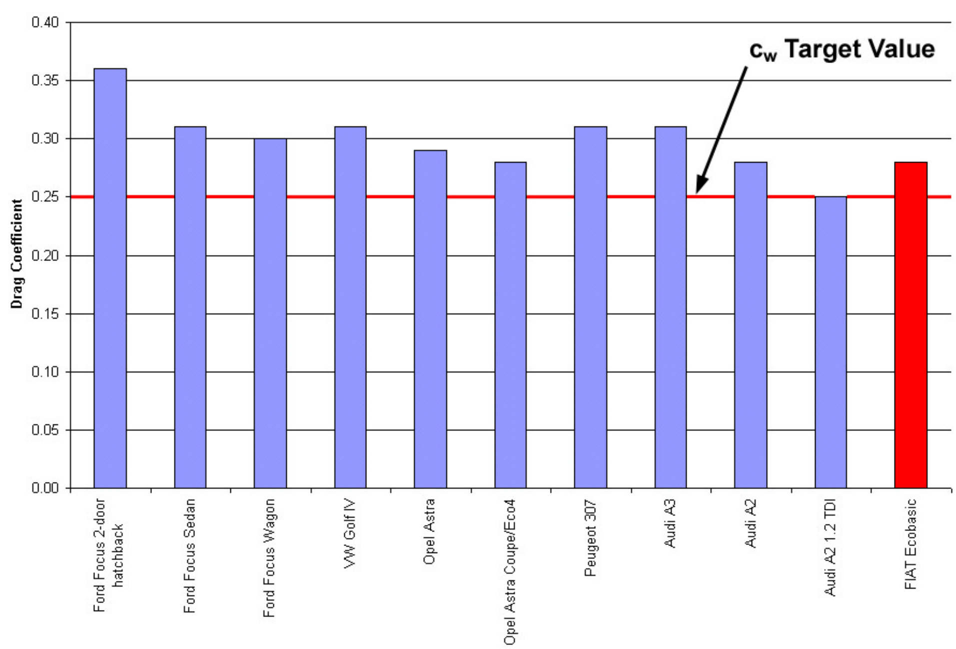


**Figure 11.2.1-1 Benchmarking aerodynamic drag coefficients C-Class vehicles**

The benchmark data for the different versions of the Ford Focus are included to illustrate a typical current range of drag coefficients derived from a common platform and frontal design.

### 11.2.2. Benchmarking PNGV/PNGV-Class Vehicles

Benchmarking data of aerodynamic drag coefficients for current PNGV-Class vehicles were gathered through publicly available information (e.g. internet, OEM publications). The following PNGV-Class vehicles were selected for benchmarking.

- Audi A6
- BMW 520
- Ford Taurus
- Chrysler Concorde

For the benchmarking of PNGV prototype vehicles, the current OEM publicized values for the $c_w$ of these vehicles were gathered. These vehicles include:

- GM Precept
- Chrysler Dodge ESX3
- Ford Prodigy

The results in Figure 11.2.2-2 show the PNGV prototype vehicles (shown in red), which are optimized for low aerodynamic drag, with significantly reduced $c_w$s versus the current production PNGV-Class vehicles (shown in purple).

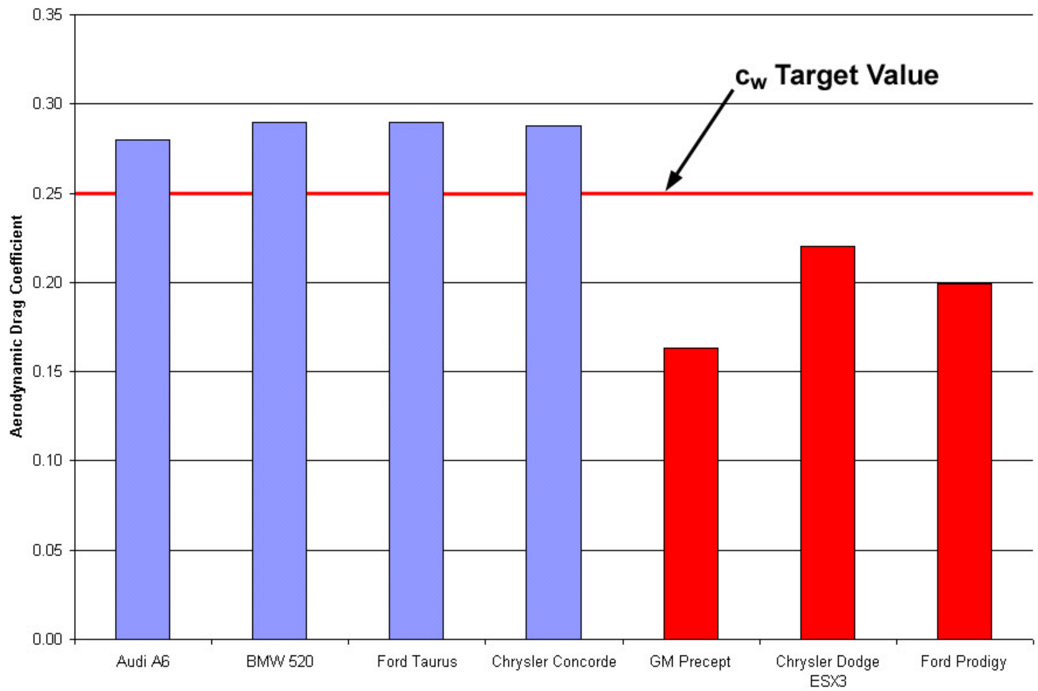


**Figure 11.2.2-1 Benchmarking aerodynamic drag coefficient data PNGV/PNGV-Class vehicles**

These low aerodynamic drag coefficient of the PNGV vehicles have been achieved through intensive wind tunnel testing and other measures, such as, underfloor cover and the replacement of outside rear view mirrors with camera systems.

The PNGV/PNGV-Class vehicles show a range of aerodynamic drag coefficients from 0.16 to 0.28.

## 11.3. ULSAB-AVC CFD Calculation

Our purpose within the ULSAB-AVC project was to use Computer Fluid Dynamic (CFD) analysis as a visualization of the computed flow field data in a virtual wind tunnel. This allowed evaluation of the aerodynamic concept from the very beginning of vehicle concepts, where no hardware models were available.

Utilizing the CFD program Powerflow®, an initial analysis was done to investigate the aerodynamic drag quality of both the C-Class and PNGV-Class vehicles. The analysis models were developed including measures to achieve low $c_w$ coefficients.

The measures included:

- Covered underbody
- Guided cooling airflow through vehicle
- Reduced frontal surface area (elimination of rear view mirrors)

These concept designs would be optimized in a further development phase, which would include additional CFD analysis and the necessary wind tunnel testing and validation.

## 11.4. Aerodynamic Drag Analysis Results

The initial streamline flow patterns derived from the aerodynamic drag analyses using Powerflow® are detailed below. The analyses were conducted with turning wheels on a moving plane (road) and included the radiator air stream through the tunnel.

### 11.4.1. C-Class Vehicle

For the C-Class vehicle, two aerodynamic simulations were performed. The first simulation (base line) showed streamlines that could be readily improved and therefore, it was decided to do an iteration (iteration 1) with an add-on rear spoiler and modifications to the underfloor behind the rear suspension by changing the angle of the panel in order to get a better airflow in this area.

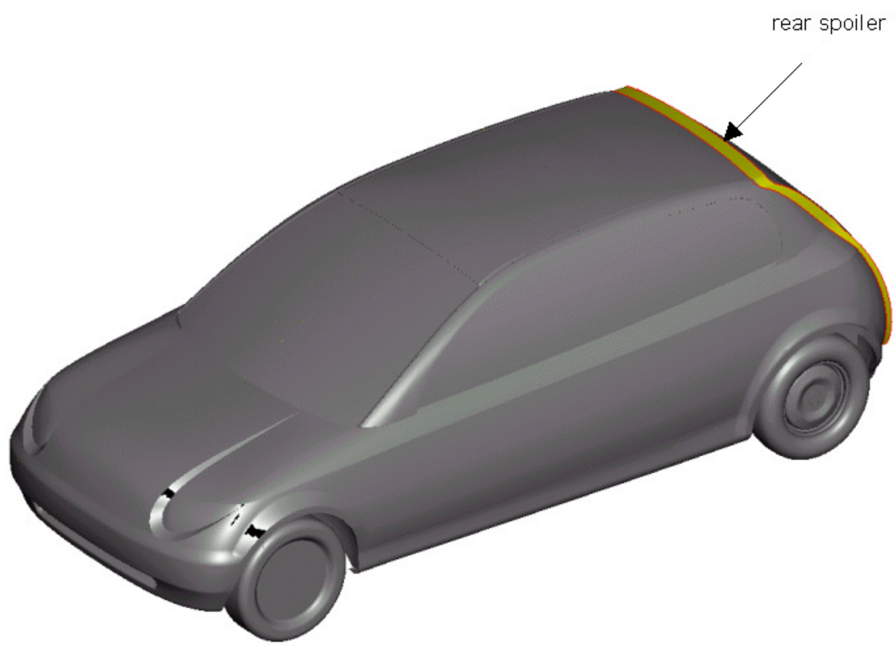


**Figure 11.4.1-1  C-Class vehicle aerodynamic model with rear spoiler added**

### 11.4.1.1. Aerodynamic Simulation Streamlines on the Surface

Figure 11.4.1.1-1 C-Class baseline rear view

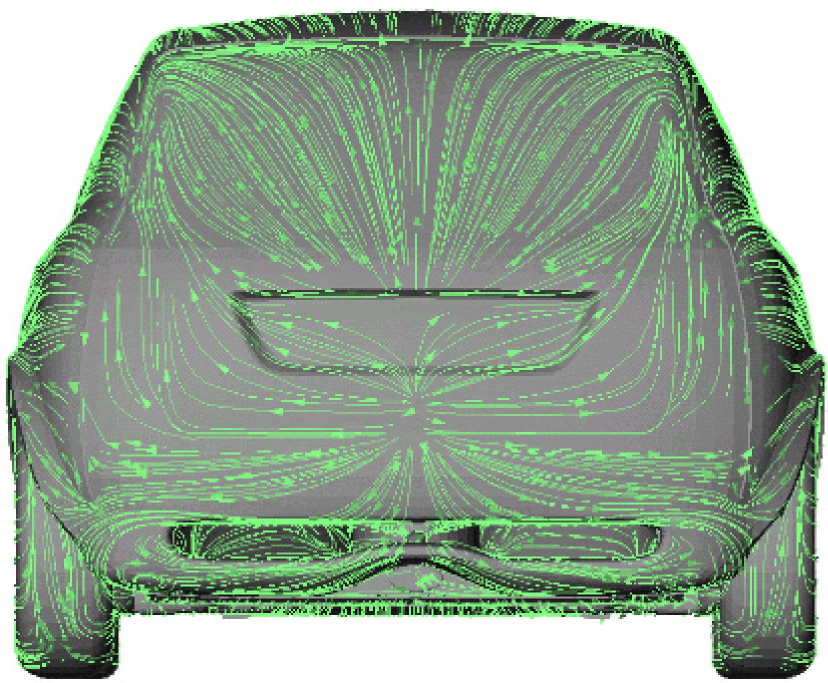

Figure 11.4.1.1-2 C-Class iteration 1 rear view

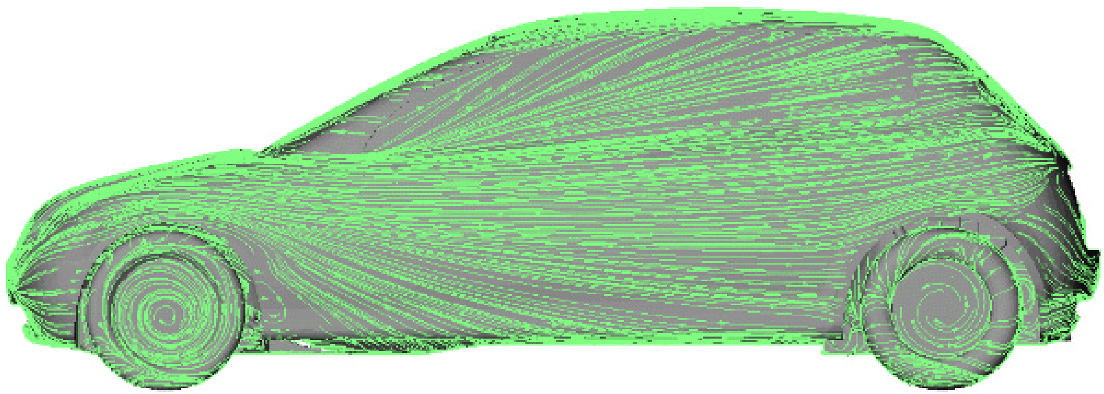

Figure 11.4-1.1-3  C-Class baseline side view

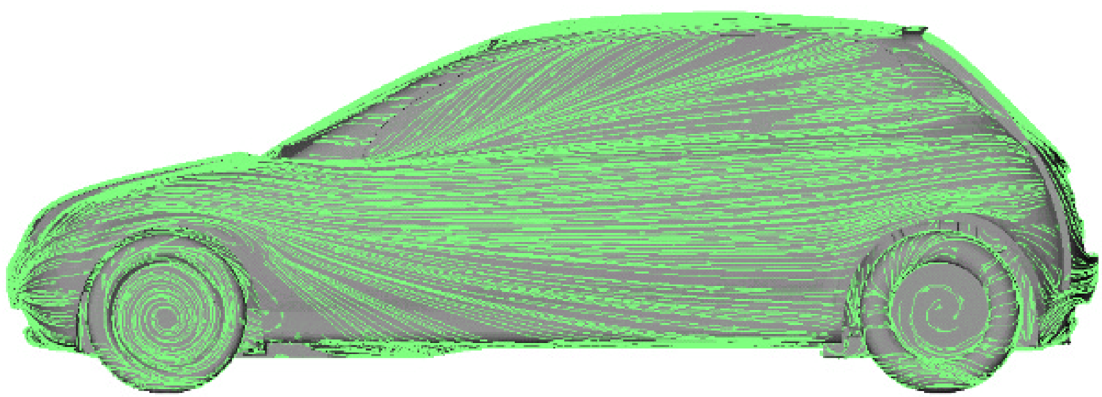

Figure 11.4.1.1-4  C-Class iteration 1 side view

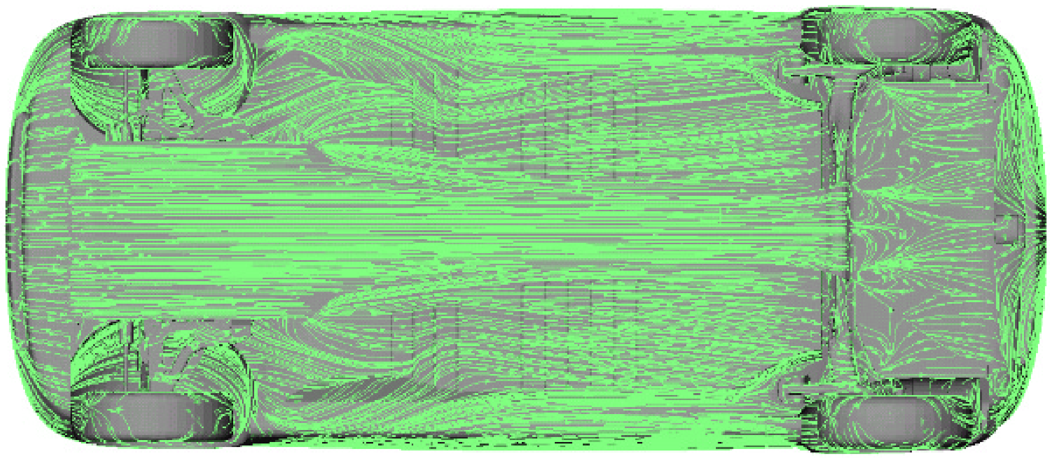

Figure 11.4.1.1-5  C-Class baseline under view

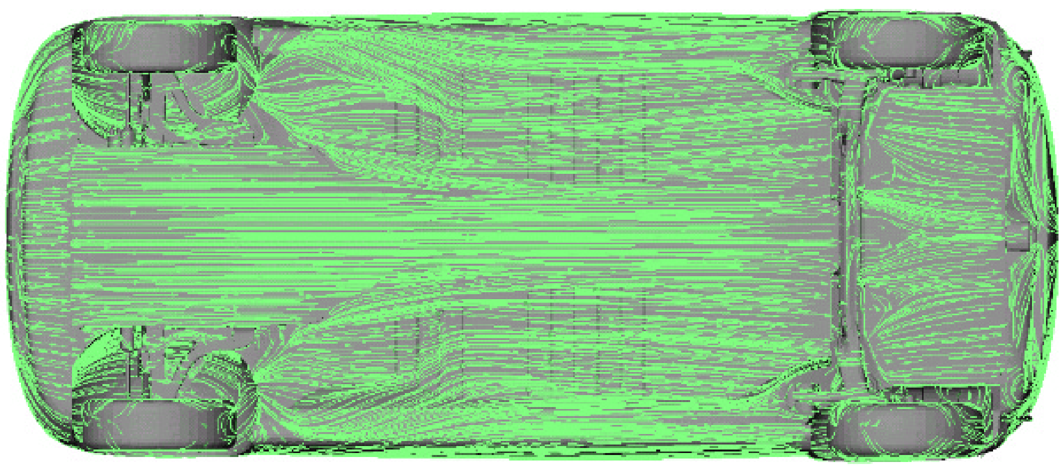

Figure 11.4.1.1-6  C-Class iteration 1 under view

#### 11.4.1.2. Streamline Velocity Magnitude

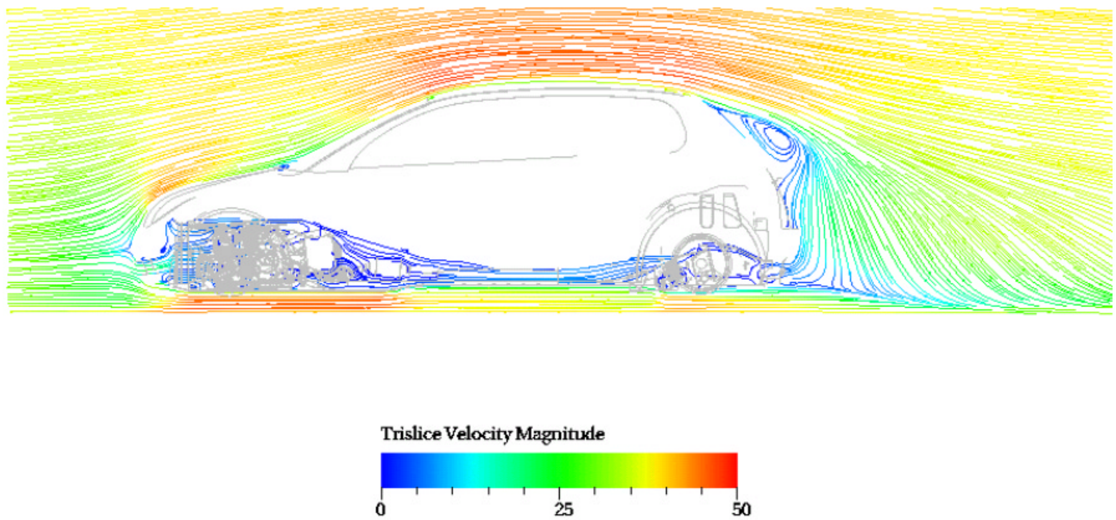


**Figure 11.4.1.2-1 C-Class base line streamlines in section y=0**

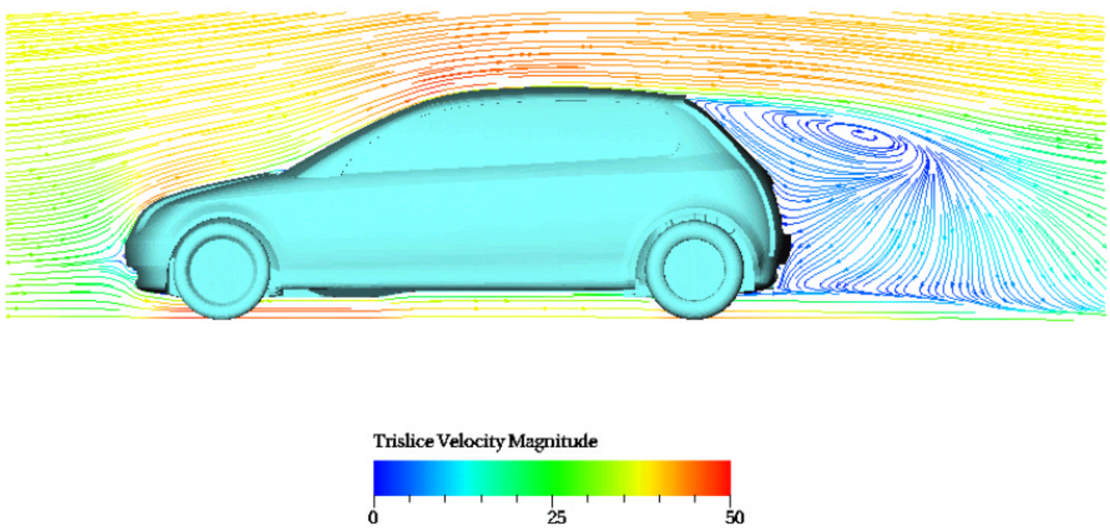


**Figure 11.4.1.2-2 C-Class iteration 1 streamlines in section y=0**

### 11.4.1.3. Summary of Aerodynamic Analysis – C-Class

The streamlines and velocity flow data presented above from these initial simulations clearly indicated the benefits resulting from the addition of the rear spoiler and other alterations. As previously stated C-Class hatchback vehicles of similar size are already in production that have achieved aerodynamic drag coefficients of between 0.25 and 0.30. The results from this initial study of the aerodynamic performance of the C-Class vehicle confirm the potential to achieve the target $c_w$ of 0.25. Details of the recommendations for further optimization are provided in Section 11.5. These recommendations will not affect the package specifications or structural performance of the vehicle.

### 11.4.2. PNGV-Class Vehicle

#### 11.4.2.1. Aerodynamic Simulation Streamlines on the Surface

Figure 11.4.2-1 through 11.4.2-4 show the computed streamlines on the surface of the ULSAB-AVC PNGV-Class.

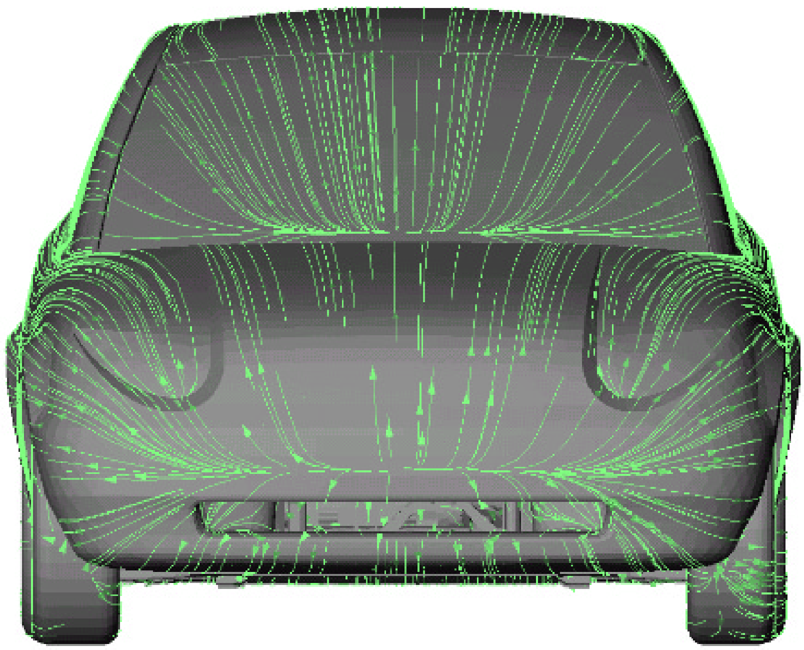

**Figure 11.4.2.1-1 PNGV-Class streamlines on surface front view**

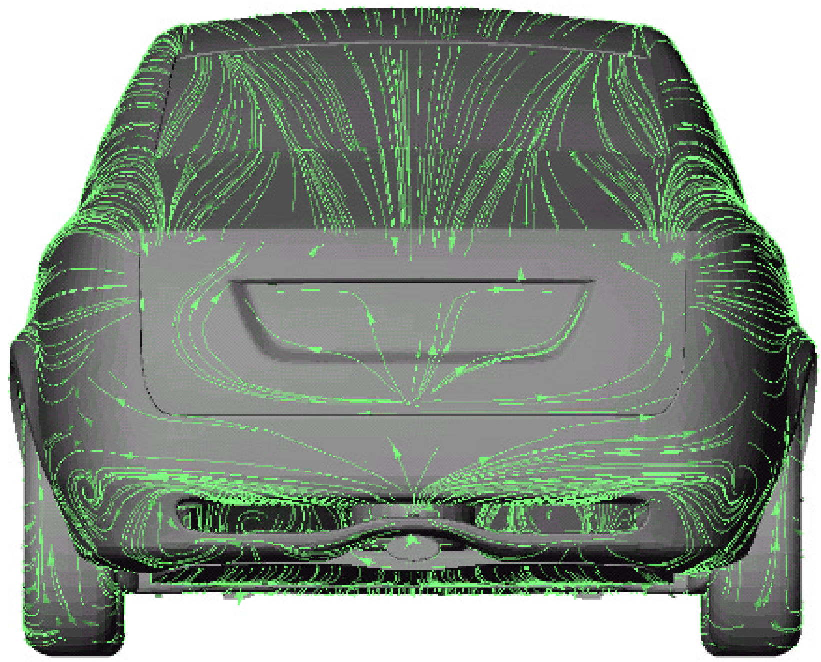

**Figure 11.4.2.1-2 PNGV-Class streamlines on surface rear view**

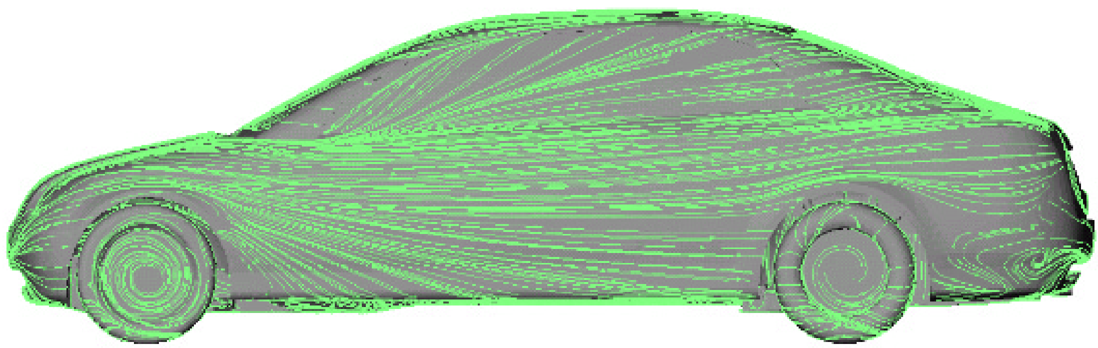

**Figure 11.4.2.1-3 PNGV-Class streamlines on surface side view**

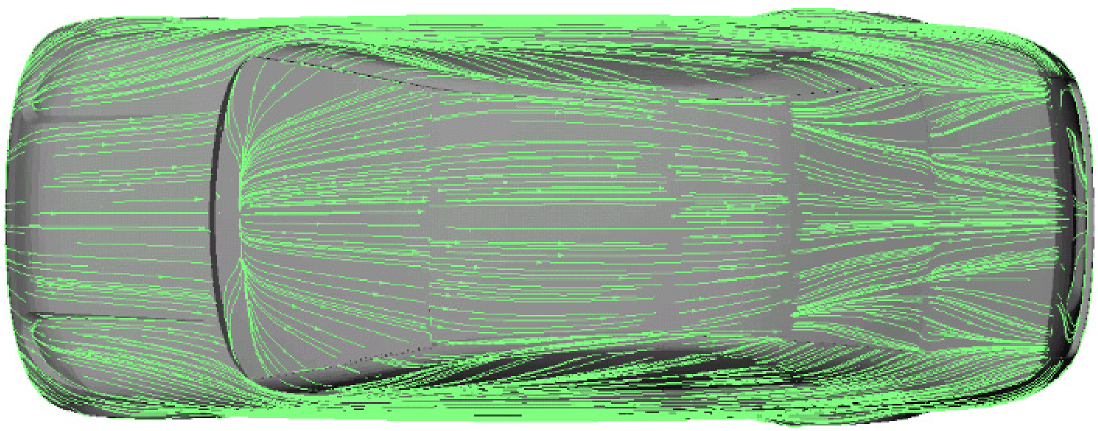

Figure 11.4.2.1-4  PNGV-Class streamlines on surface top view

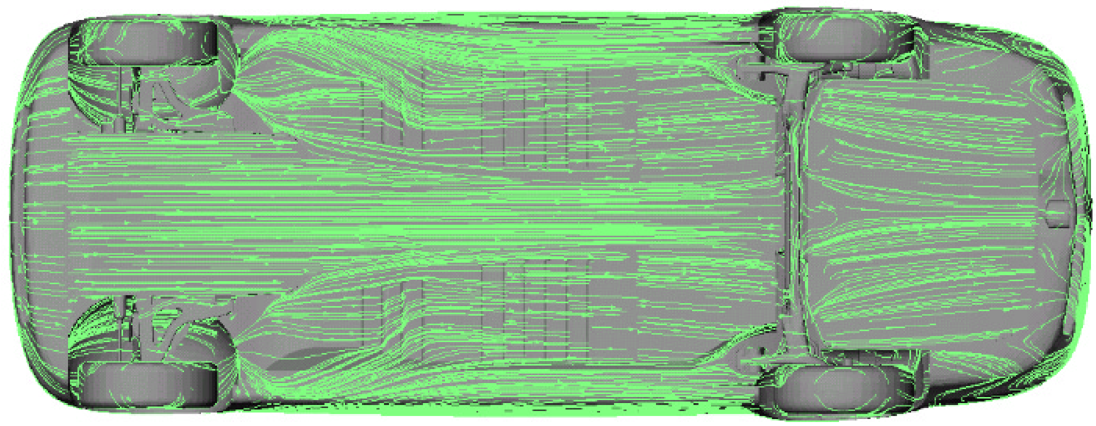

Figure 11.4.2.1-5  PNGV-Class streamlines on surface under view

### 11.4.2.2. Streamline Velocity Magnitude

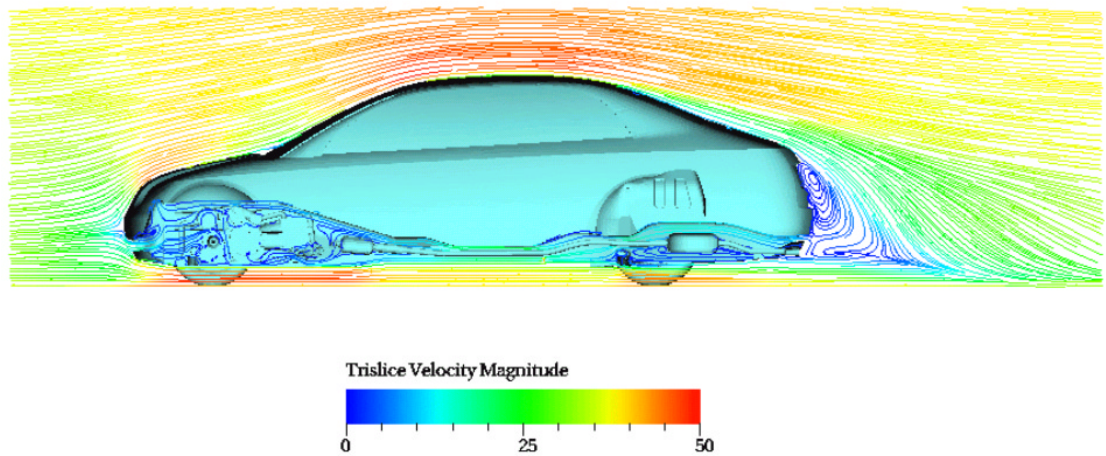


**Figure 11.4.2.2-1 PNGV-Class streamlines in section y=0**

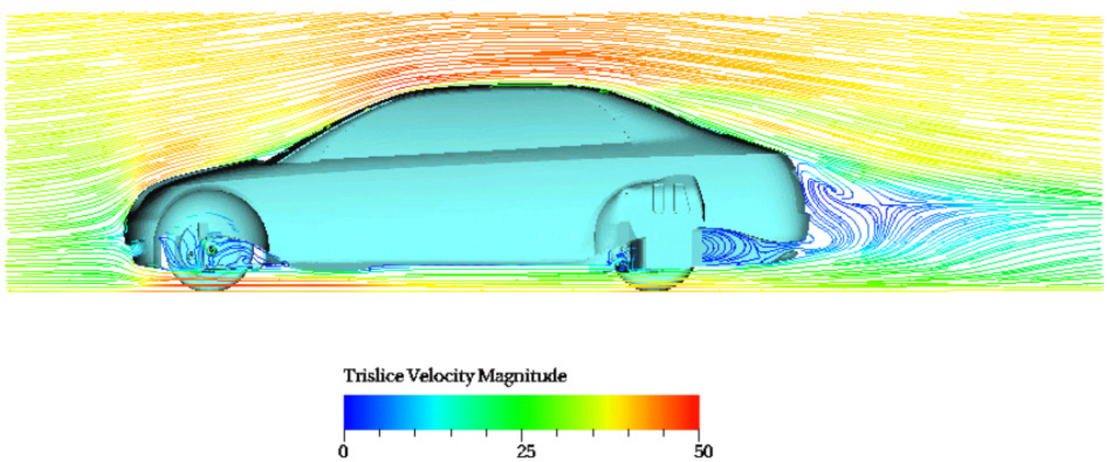


**Figure 11.4.2.2-2 PNGV-Class streamlines in section y=400**

### 11.4.2.3. Summary of Aerodynamic Analysis – PNGV-Class

The streamline and velocity flow data presented above from the initial simulations indicate that the PNGV-Class vehicle already demonstrates a credible aerodynamic quality. As previously stated, fully developed PNGV-Class and PNGV prototype vehicles, have achieved aerodynamic drag coefficients of between 0.25 and 0.29 and 0.16 and 0.22 respectively. The results from this initial study of the aerodynamic performance of the PNGV-Class vehicle confirm the potential to achieve that target cw of 0.25. Details of the recommendations for further optimization are provided in Section 11.5. These recommendations will not affect the package specifications or structural performance of the vehicle.

## 11.5. Summary and Measures for Future Optimization

The interpretation of the initial computed flow field data led to the following conclusions for future aerodynamic optimization to be evaluated during the further development of these vehicle concepts through the use of CFD analysis and wind tunnel testing.

For the C-Class vehicle:

- Reduction of tail area
- Optimization of position, size and angle of rear spoiler
- Optimization c-pillar radii in rear window area
- Optimization of radii to create a tearing edge in rear light area

For both vehicles:

- Development and optimization of the rear floor behind the rear suspension to create a diffuser
- Development and optimization of a cover for the rear suspension pick-up points to the body structure
- Optimization of body shape behind the rear wheels to create more cover of rear wheels
- Development and optimization of tearing edge at the transition of the rear floor pan to rear fascia
- Development and optimization of aerodynamic devices in front and rear of the front and rear wheels

- Optimization of airflow through radiator module
  - ⇒ The analysis has shown a sufficient air mass flow through the radiators for the selected ULSAB-AVC engines. Further detailed optimization should include an alternative radiator arrangement together with an investigation of air outlet into the wheelhouse. The radiator module could be arranged in a way where a wider and thinner radiator for the cooling water and the air conditioning condenser could be placed in front of the cooling water radiator besides the intercooler (diesel variant) as shown in Figure 11.5-1.

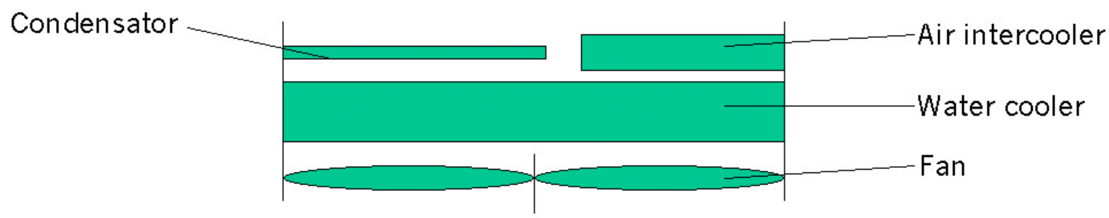


**Figure 11.5-1 Rearrangement of radiator**