A review of “performance analysis and optimization of car air spoilers”

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Abstract. Before last decade, due to surplus amount of fuel, cars are designed for high speed operation, comfort and safety. As scarcity of fuel increases due to high consumption of fuel in automobiles, many researchers started working on the idea of alternative fuels, redesign of car body and reducing aerodynamic losses. To overcome these losses spoilers are used and hence it is needed to optimize its shape. This study is primarily focused to find out optimized shape of car spoiler so that mass can be minimized which help in reducing fuel consumption without affecting its aerodynamic properties and strength. Computational Fluid Dynamics (CFD) analysis of two dimensional model of spoiler is done whose results are validated by earlier research work in this field for understanding variation of aerodynamic property of cross-section. Three dimensional CFD analysis of spoiler gives aerodynamic property and pressure data which is needed to compare result of optimized model formed by optimized cross-sectional shape. Shape optimization is done by Shape Optimization tool of ANSYS 14.0 which is further tested for design failure in ABAQUS 6.11. The result of shape optimization has saved 18.74% of material keeping all its strength and aerodynamic property intact. This study open provides a numerical tool for improvement of future model of spoiler in terms of reduction of mass.

Keywords: Car Air spoiler, Coefficient of lift, Coefficient of drag, Shape optimization, Stress analysis.

1. Introduction

In early nineties there was ample amount of fuel oil was available in market, but as there is scarcity of fuel oil started, there is a hike in fuel prices. Earlier main aim of car’s design was high-speed operation, comfort and safety only. As hike in fuel was there many people started thinking on various aspects to overcome this problem and increase sale of automobile industry. Besides the idea of alternative fuel, losses due to aerodynamics are also main concern of many researchers. In India due to strengthen economy sales of transportation vehicle especially cars has increased a lot since 2000.

This study is focused on optimizing shape in such a way, that mass is reduced keeping all its strength, coefficient of drag ($C_D$) and coefficient of lift ($C_L$) same. Fuel saving potential of drag reducing devices, which can be fitted on heavy vehicle is studied by a numerical study and found that these devices reduce fuel consumption up to 9%. The annual saving of fuel ranges from 600 to 2600L [1].

Shape optimization considers all constraints on geometry, stress, displacement etc. Under all these constraints it will provide a new optimized shape to two dimensional (2D) or three dimensional (3D)
components with minimum mass or weight. In emerging world of faster computers, powerful structural analysis and optimization can be done to improve design in an efficient manner. It is suggested to pay attention on shape optimization algorithms which can solve mechanical design problem in a better suitable way [2].

The major problem of drag reduction in car is keen topic since last decade and hence comes in picture computational cost and its complexity. Drag minimization of 3D car model using concept of Computational Fluid Dynamics (CFD) is validated through experiments so that it can be used for further design modifications [3].

Spoiler are analyzed on the basis of aerodynamics properties and earlier not very much work is done in field of shape optimization of spoilers using Finite Element Method (FEM) techniques and Shape Optimization tool of ANSYS 14.0 to reduce the mass and fuel consumption.

1.1 Spoilers Aerodynamics
Spoilers are aerodynamic device used in automobiles and faster moving cars to remove turbulence across body of car. It is attached to an automobile. One of the problems for vehicles is to control wake. Suggested method is to change rear body shape and change of shape of spoiler and result of experiments is a great reduction in value of $C_D$ and $C_L$ [4] Reduction is shown in ‘figure 1.1’

![Figure 1.1. Result of pre-tests for new shape(Fukuda, et al. 1995)](image)

1.2 Function of Spoilers
Spoilers help to reduce form drag and aerodynamic noise both at same time. In addition, it also reduces lift and improves traction leading to better maneuver [5]. This study defines that intended function of this device is to spoil unfavorable air movement across body of vehicle of some kind in motion. The main function of a spoiler is diffusing airflow passing over and around a moving vehicle as it passes over vehicle. This diffusion is accomplished by increasing amounts of turbulence flowing over shape, “spoiling” the laminar flow and providing a cushion for the laminar boundary layer.
1.3 Working of Spoilers
Spoilers working can be understood by help of concept of uplift of airplane wing. As shown in ‘figure 1.2’ air moving bottom to wing will travel shorter distance as compared to air moving on top surface of wing which creates a pressure difference and creates an uplift of wing.

![Figure 1.2. Airflow around airplane wing.](image)

A car experiences various types of lift, drag and down force due to its shape. These forces are shown in ‘figure 1.3(a)’. So when down force is needed inverted wing is used as in case of spoilers. Spoiler helps to turn upper airstream in direction as shown in ‘figure 1.3(b)’, so that airstream causes down forces at rear end. In this way spoiler reduces uplift at high speed.

![Figure 1.3 (a) Airflow around car without spoiler](image)

![Figure 1.3 (b) Airflow around car with spoiler](image)
2. Material Analysis

Yet again fuel consumption is studied and tried to be reduced by changing conventional material to advanced material. These reforms must be taken care to meet high future demand specifications. In this context suggested material for spoilers is unreinforced thermoplastic [6]. The most common material in this class is Acrylonitrile Butadiene Styrene (ABS) plastic. For better strength and stress absorption capacity fabrication to be done using sandwich construction in which ±45° orientation of fibers with foam gives better result than ±45° orientation of fibers without foam [7]. Another recent material suitable for spoilers is soft morphed materials. soft morphing structures are capable of continuous curvilinear structural deformation upon actuation without discrete sections that generate aerodynamic losses [24]. fabricated a woven type smart soft composite consisting of shape memory alloy wires and glass fiber-reinforced composite and applied to the rear spoiler. To verify its aerodynamic performance, wind tunnel experiments were carried out using a stand-alone spoiler under various wind speeds, angles of attack then the spoiler was mounted on the small-scale car and wind tunnel tests were conducted to determine the potential of augmentation on aerodynamic performance by implementing the soft morphing spoiler.

3. Design Analysis

Comparison of various aspects (likes shape, material) in designing Human Powered Vehicles on various road conditions is studied and found that magnitude of drag depends on physical appearance such that body shape, accessories attached, extrusions etc. [8]. A comparative analysis of lift and drag on sedans with and without back spoilers and the hatchbacks with and without front spoilers was performed. The study was based on three turbulence models which showed that the drag marginally increases and the lift decreases by using the spoilers. The decrease in lift increases the down force and this overcomes the effect of increase in drag [19]. The aerodynamic impacts on sedan car’s fuel economy due to different spoilers mounted on different locations on the car back side was presented. They performed the CFD analysis of 3D computer model of 4-door sedan cars which was created on solid works and presented the coefficient of lift and drag values for each of the spoiler combinations [22].

For smooth flow around spoiler six basic shapes of rear spoiler have been studied and numerical simulation is performed for analysis of stability and noise produced. This analysis suggest that among six shapes case 4, which is an aerofoil shape, has made flow smooth with lower noise level and proposed for spoiler shape ‘figure 2’. In fact it smoothens flow and reduces turbulence at tail [12]. Two spoiler models, NACA 4412 and NACA 6409 were incorporated on a car rear side and tested to obtained the lift and drag forces for each spoiler model. The models were created on 3D software CREO and analysis was performed on CFD workspace at different air speed to investigate the performance parameters [21].

![Figure 2](image-url)
4. CFD Analysis
As CFD tool is an important tool in analyzing fluid behavior. Many studies have been performed in order to get best results and validation. Modelling car geometry and analyzing for CFD gives results like experiments and behavior is predicted in advance and effect of applying spoiler on rear part of car is studied by making a basic car model and running CFD simulation to find $C_D$ and $C_L$ values first without spoiler and then with spoiler and found percentage reduction in $C_D$ and $C_L$ value be 1.7 and 4 respectively [9]. A similar study has been performed later with different model of car and found drag was reduced by 2.02% while lift reduction was exceptional 14.06% [10]. Analysis of wake flow-field, downstream of a square back car model to investigate the combined effect of horizontal and vertical deflectors was presented. They found that vertical deflector’s height was playing a key role in this scenario markedly affecting the resulting drag and lift coefficients. Analysis of velocity fields pointed out the existence of an optimal vertical spoiler size, in the presented set-up equal to $2/3$ of model height, which featured the overall best performance compared to other tested configurations. The beneficial effect of combined spoilers was found to be more relevant when horizontal and vertical deflectors feature a moderate (20°) slant angle with respect to free stream direction [16]. Comparison of large eddy simulations (LES) and the wall modelled large eddy simulations (WMLES) was done on the flow over a realistic generic car geometry and a 70% CPU time reduction was obtained using the WMLES [18]. A RANS – based CFD analysis was performed to find the impact of different spoiler angles on the lift and drag forces of hatchback vehicles. The numerical results showed that at positive spoiler angle, the aerodynamic lift of the hatchback model reduced up to 2937% however the spoiler effect was unfavorable to lift reduction when configured at negative inclination angle. Although the lift was found to decrease with increase in spoiler angle [20].

5. Shape Optimization
(Hsu 1994) Shape optimization is defined as a set of geometrical modelling, structural analysis and optimization. In primary step of making design model, geometrical representation of boundary shapes and design variable are defined. The design optimization problem thus can be written as:

Minimize $f(x)$
Subject to $g_1(x) \leq 0$
$g_2(x) \leq 0$

where $x$ is vector of design variable, $f(x)$ is objective functions, $g_1(x) \leq 0$ and $g_2(x) \leq 0$ are constraints. Further analysis model is created separately by help of design model. Choice of analysis technique depends upon converting design model into analysis model, capability and accuracy of analysis technique. In next steps optimization algorithm is used to optimize component. The flowchart for shape optimization process is shown in ‘figure 3’. Multi objective optimization using FEA and Multi Objective Genetic Algorithm (MOGA) are solved to find all Pareto’s optimal solutions in one go. Earlier multi objective optimization is solved by transforming function into single objective function. It is found that MOGA is better alternative for multi objective optimization of auto panel drawing die face design [12]. ANSYS’s Shape Optimization tool has been used to reduce weight as well as cost of steel connecting rod. They used weight and cost as their objective function keeping geometry and manufacturing cost as design variable and constraint respectively. They found that using ANSYS easily it can optimize shape of component which in their case is 10% and 20% weight reduction keeping cost in direct relation to weight [10].
6. Conclusions
An ample amount of work on car air spoilers has been done but most of the researches emphasizes on reduction of coefficient of drag ($C_D$) and coefficient of lift ($C_L$) by the relative wind. But the modern researchers like [12] and [10] have done very well in the field of optimization with the help of which the mass of spoilers can be reduced for a given spoiler keeping its coefficient and coefficient of drag the same. After reviewing a plenty number of research papers, we have reached on following conclusions.

1. $k$-$\varepsilon$ turbulence model is used for CFD calculation which provides value of $C_D$ and $C_L$ at different angles of attack both for 2D and 3D analysis which gives idea of accuracy of model and reliability of software package.

2. FEA can be done with the help of pressure variation around spoiler which is found in 3D analysis and can suggest that model is having what amount of maximum stress which is equivalent to a safe design having some desired factor safety.

3. Shape optimization tool of ANSYS 14.0 is very useful and easy to understand which provides the shape of spoiler with a reduced mass keeping all $C_D$ and $C_L$ values almost same but it gives some maximum stress. The most common material for the fabrication of spoilers is ABS plastic, because of its better strength and the stress absorption capacity. And a good amount of mass can be reduced by making section of spoiler hollow. However doing so increases maximum stress but it is not leading system failure.

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