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DRAG REDUCTION IN AUTOMOTIVE VEHICLES

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Abstract- Drag is a force acting on a vehicle when it is dynamic state, this drag force is acting due to the opposing wind. Coefficient of drag is the way the drag force acting on a vehicle is calculated . The main objective of this paper is to study and analyze the drag in various automotive scenarios and study diverse/advanced principles and methodologies with respect to countering the inefficiencies caused due to drag in automotive vehicles used to reduce drag in automotive vehicles.

I.INTRODUCTION

In this paper, there are four different segments in which, various methodologies and techniques were used for reducing the aerodynamic drag. The four segments are hatchbacks, sedans, suv's and truck. It is to know how the various methods, attachments and modifications help in redirecting the air flow by helping in reducing the drag of the vehicle.

II.DRAG REDUCTION IN TRUCKS

When air vanes are mounted on the tractor trailer of the truck, both in the front and the back of the trailer, these air vanes divert the air flow by which a reduction 36% of drag in the front and 3-6% of drag in the rear is observed. The front and rear air vanes are used to direct the airflow, even by curving the trailer edges the drag can be reduced [1] [38-50]. When underbody fairing was introduced to the tractor trailer one with a slit in the center of the fairing, 17.5% reduction in drag was observed and without the slit in the center of the fairing, 18.6% reduction in drag was observed. By using underbody fairing the drag can be reduced but the one without the slit shows more reduction in drag than that with the slit [2]. When an underbody fairing was introduced to the cab of the truck, this underbody fairing helps in diverting the air flow, by which an 11% reduction in drag was observed. Using fairings under the cab of the truck helps in reduction of drag [3]. By optimization and modifying the trailer and cab dimensions such that 30% of reduction in drag is been observed. By modifying the dimensions of the trailer and the cab to support aerodynamics, the drag can be reduced [4]. When the deflectors or to say wind deflectors are mounted on the cab of the truck, they help in diverting the air flow, by which a 13% reduction in drag is observed. Using aerodynamically designed cab mounted deflectors the reduction in drag can be obtained, by using non aerodynamically designed deflectors the drag can increase instead of reducing [5][6]. When side extenders, side skirts and aft-body plates are mounted under the trailer to divert the air flow, 23% of reduction in drag is observed. By using side extenders, skirts and aft-body plate the drag can be reduced but the most effective change in drag is observed when side skirts are used [7]. When deflectors, air-shield deflectors, nosecones are mounted, when the gaps are sealed, a significant amount of decrease in drag is observed due to increase in fuel economy. Using cab mounted deflectors like air-shield deflector combined with nosecone and an air-shield gap seal provide more reduction than using them individually [8]. When deflector vanes, convex fairings are mounted on the trailer and the edges of the trailer are being rounded, 33% of reduction in drag is observed. The drag can be reduced using deflector vanes, convex fairings and rounding the edges to divert the air flow [9]. By mounting wind deflector on the top of the trailer, 9.73% of reduction in drag is observed. The purpose of using a wind deflector is to reduce the effect of air flow to reduce the drag [10]. On creation slots and trufts at rear end of the tractor trailer the air flow can be deflected upon which drag can be reduced [11]. By curving the edges and using diffuser diverts the air flow which decreases drag [12]. The double plate side skirts divert the air flow such that the drag force acting on the truck is reduced [13]. Using a combination of air deflectors on the cab and rear, side skirts and the wheel axle fenders the air flow can be diverted in such a way that the turbulence is created after the vehicle instead on it which ensures that there is less drag acting on the vehicle [14]. (Table no 1: Drag reduction in trucks.)

III.DRAG REDUCTION IN HATCHBACK

When a tail plate is mounted in the rear of the hatchback to divert the air flow, 0.078% reduction in drag is been observed. Using tail plate, the air flow can be diverted which helps in reducing drag [15] [64-73] By modifying the geometry of the spoiler, c-pillar holder of the spoiler, right and left side mirrors, 4.2% of reduction in drag was observed. By using adjoin method and solver, detecting the surface sensitive parts and morphing the geometry of those parts the drag can be reduced [16] By morphing the geometry of the external body parts of the hatchback in such a way that the air flow is diverted, 10.34% of reduction in drag is been observed. By optimization process the various parts which cause the drag can be determined and by modifying the geometry of those parts the drag can be reduced [17] By introducing a vortex generator the air flow can be diverted, 90% reduction in drag can be observed. By using the vortex generator, the air flow can be diverted which helps in reducing the drag [18] When a full under-floor, wheel arch under-side cover, intake blank, gap seals, front wheel spoilers, rear wheel-arch cover, under-floor diffusers, box cavity are introduced and rear view mirrors are removed, 25% of reduction in drag is been observed. By using diffusers, sealing gaps, wheel-arch covers and introducing box cavity the drag can be reduced [19] By mounting a spoiler in the back of the hatchback to divert the air flow, 20-30% of reduction in drag is been observed. The use of spoiler helps in deflecting the air flow which intern reduces the drag [20] By introducing a vertical splitter in the rear of the hatchback, 27-45% of reduction in drag is been observed. Using a vertical splitter helps is redirecting and splitting the air flow which intern reduces the drag [21]. (Table no 2: Drag reduction in hatchback.)

IV.DRAG REDUCTION IN SUV'S

When immersed boundaries are applied on the SUV in computational fluid dynamics, 3-7% of reduction in drag is been observed. Using immersed boundaries, the drag coefficient can be reduced, by predicting the aerodynamic flow around the SUV and diverting air flow using curved body panels [22]. By using body cavities and air bleeding the air flow can be diverted, 3.3% of decrease in drag is observed due to use of body cavity and 0.3-1.1% of decrease in drag is observed due to use of air bleeding. Aerodynamic drag reduction can be accomplished by restructuring the low pressure wake. External cavities can increase the drag, while the body cavities can reduce the drag. Air bleeding around the periphery of the base area can also reduce the drag but it all depends on the outlet location [23]. On introducing fairings in the rear of the SUV, screen and vortex generator in the front of the SUV, 26% reduction in drag due to fairings, 6% reduction in drag due to vortex generator and 1.24% reduction in drag due to screen is been observed. By using rear screen, introducing a fairing in the rear, the air flow can be diverted in such a way that a significant amount of drag can be reduced [24]. On using a boat tail at an angle of 10 and 15 degrees, a significant reduction in drag is observed due to increase in fuel economy. Using boat tail, the aerodynamic drag can be reduced by diverting the air flow and setting it at an optimum angle of 10 and 15degrees [25]. By installing bonnet strakes and rear pillar spoiler, the air flow can be diverted, by which -0.01 value of

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coefficient of drag is observed, that indicates that there is a decrease in drag. Using rear pillar spoilers and bonnet strakes the drag can be reduced by diverting the air flow [26] [51-63]. By changing the angle of the radiator and the position of the radiator, -0.01 value of coefficient of drag is observed, that indicates that there is a decrease in drag. By changing the position and angle of the radiator in such a way that the air flow is diverted into the engine and not under the body of the vehicle the drag can be reduced [27]. When front canopy and side skirts are mounted on the SUV to divert the air flow, -0.5 to -0.3 value of coefficient of drag is been observed, that means that there is a significant amount of drag reduced. Using front canopy and side skirts, the air flow can be redirected and drag can be reduced [28]. On introducing a lid that closes the pickup truck trailer the drag can be reduced [29]. (Table no 3: Drag reduction in SUV's.)

V.DRAG REDUCTION IN SEDANS

When the angle of the outer shell of the externally attached trailer of the sedan is changed in such a way that the air flow is diverted, a significant amount of drag is being reduced. By varying the angle of the trailer outer shell i.e., making it into a reverse aero foil shape the air flow can be redirected and drag can be reduced [30]. On introducing a trunk lid kick up the air flow can be diverted, 7.1% of drag reduction is observed. By using a trunk lid kick up the drag can be reduced by reducing COANDA flow [31]. By mounting a boat tail in the rear of the sedan, 18.8% of reduction in drag is been observed. The boat tailing technique is effective in reducing the aerodynamic drag of the automobile, aero foil profile gives best overall performance and helps reducing drag [32]. On using front and rear spoiler, diverting the air flow, -0.039 value of coefficient drag is observed; this indicates that there is a reduction in drag. Using front and rear spoilers helps reducing the drag by redirecting the air flow [33]. By packing the engine bay, redistributing the cooling air flow exit the reduction in drag is observed. The change in engine bay packaging, redistributing the cooling air flow, the air flow along the underbody can be reduced, by which drag can be reduced [34]. The rear spoiler helps in diverting the air flow which reduces drag [35]. The lateral tapering of the rear end and the introduction of spats near the wheels diverts the air flow which intern reduces the drag [36]. (Table no 4: Drag reduction in Sedans.)

CONCLUSION

Drag can be reduced by diverting the air that is opposing the motion of the vehicle. This can be done in various ways either by morphing the geometry of the vehicle, by adding deflector to the vehicle, changing the intake air flow exit, closing the air gaps, reducing sharp edges in the body panels and also by making an aero foil shaped vehicle which has very minimal drag. In the above tabular column, these various methods, attachments and modifications to the body geometry are being discussed which help in reduction of drag.

Table no. 1: Drag reduction in trucks

Area where the attachments and modifications are performed to reduce drag	Drag reduction attachments and modifications	Drag reduced	Result and discussion
Tractor trailer of the truck	Air vanes mounted in the front and rear of the trailer	36% front & 3-6% rear	The front and rear air vanes are used to direct the airflow to reduce the drag, even by curving the trailer edges the drag can be reduced[1].
Tractor trailer of the truck	Underbody fairing with a slit in the between and without	18.6% without & 17.5% with slit	By using underbody fairing the drag can be reduced but the one without the slit shows more reduction in drag than that with the slit[2].
Cab of the truck	Underbody fairing	11%	Using fairings under the cab of the truck helps in reduction of drag[3].
Underbody of tractor trailer	Double plate side skirts	5.8% increase in fuel economy by reduced drag	The double plate side skirts divert the air flow such that the drag force acting on the truck is reduced[13].
Tractor trailer and Cab	Curving the edges using diffusers	Drag is reduced	By curving the edges and using diffuser diverts the air flow which decreases drag[12].
Tractor trailer and Cab of the truck	By optimization and modifying the trailer and cab dimensions	30%	By modifying the dimensions of the trailer and the cab to support aerodynamics, the drag can be reduced[4].
Cab of the truck	Cab mounted deflectors	13% 30%[6]	Using aerodynamically designed cab mounted deflectors the reduction in drag can be obtained, by using non aerodynamically designed deflectors the drag can increase instead of reducing[5][6].
Tractor trailer of the truck	Tractor side extenders, trailer side skirts and trailer aft-body plates	23%	By using side extenders, skirts and aft-body plate the drag can be reduced but the most effective change in drag is observed when side skirts are used[7].
Cab of the truck	Cab mounted deflectors, air-shield deflector, nosecones and air-shield gap seal	Due to decrease in drag the decrease in fuel consumption is observed	Using cab mounted deflectors like air-shield deflector combined with nosecone and a air-shield gap seal provide more reduction than using them individually.[8] .
Container or trailer	Deflector vanes, convex fairings, rounding edges	33%	The drag can be reduced using deflector vanes, convex fairings and rounding the edges to divert the air flow[9].
Cab of the truck	Wind deflector on the top of the cab	9.73%	The purpose of using a wind deflector is to reduce the effect of air flow to reduce the drag[10].
Rear end of the tractor trailer	Slots and trufts	31%	On creation slots and trufts at rear end of the tractor trailer the air flow can be deflected upon which drag can be reduced[11].
Cab and tractor trailer	Deflectors on the cab. side skirts, rear deflectors and tire fenders	25%	All these extra attachments help in diverting the airflow such that there is no drag acting on the vehicle[14].

Table no. 2: Drag reduction in hatchback

Area where the attachments and modifications are performed to reduce drag	Drag reduction attachments and modifications	Drag reduced	Result and discussion
Rear	Tail plate	0.078%	Using tail plate the air flow can be diverted which helps in reducing drag[15].
External body parts	Spoiler & c-pillar holder, right and left side mirrors	4.2%	By using adjoin method and solver, detecting the surface sensitive parts and morphing the geometry of those parts the drag can be reduced[16].
External body par	Morphing body geometry	10.34%	By optimization process the various parts which cause drag can be determined and by modifying the geometry of those parts the drag can be reduced.[17].
Roof	Vortex generator	90%	By using the vortex generator the air flow can be diverted which helps in reducing the drag[18].
External attachments	Full under-floor, wheel-arch under-sides covered, intakes blanked, gaps sealed, door mirror removed, front wheel spoilers, rear wheel-arch cover, under-floor diffusers and box cavity.	25%	By using diffusers, sealing gaps, wheel-arch covers and introducing box cavity the drag can be reduced[19].
Rear	Spoiler	20-30%	The use of spoiler helps in deflecting the air flow which intern reduces the drag[20].
Rear	Vertical splitter	27-45%	Using a vertical splitter helps is redirecting and splitting the air flow which intern reduces the drag[21].

Table no. 3: Drag reduction in SUV'S

Areas where the attachments and modifications are performed	Drag reduction attachments and modifications	Drag reduced	Results and discussion
External body parts	Immersed boundary CFD	3-7%	Using immersed boundaries, the drag coefficient can be reduced, by predicting the aerodynamic flow around the SUV and diverting air flow using curved body panels[22].
Front and rear	Body cavities and air bleeding	3.3% and 0.3-1.1%	Aerodynamic drag reduction can be accomplished by restructuring the low pressure wake. External cavities can increase the drag, while the body cavities can reduce the drag. Air bleeding around the periphery of the base area can also reduce the drag but it all depends on the outlet location[23].
Rear & front	Rear fairing, screen & vortex generator in the front.	26%, 6% &1.24%	By using rear screen , introducing a fairing in the rear, the air flow can be diverted in such a way that a significant amount of drag can be reduced[24].
Rear	Boat tail angle 10 and 15 degrees	Due to decrease in drag fuel economy has increased	Using boat tail, the aerodynamic drag can be reduced by diverting the air flow and setting it at an

			optimum angle of 10 and 15degrees[25].
Front and rear	Bonnet strakes and rear pillar spoiler	0.01	Using rear pillar spoilers and bonnet strakes the drag can be reduced by diverting the air flow[26].
Underbody	Radiator angle and position	0.01	By changing the position and angle of the radiator in such a way that the air flow is diverted into the engine and not under the body of the vehicle the drag can be reduced[27].
Front and side	Front canopy and side skirts	0.5-0.3	Using front canopy and side skirts, the air flow can be redirected and drag can be reduced [28].
Pickup truck trailer	Pickup truck trailer cover	6%	By closing the opening which creates turbulence and causes drag, the drag induced can be reduced[29].

Table no. 4: Drag reduction in sedans

Areas where the attachments and modifications are performed	Drag reduction attachments and modifications	Drag reduced	Results and discussion
Trailer attached at the back	Angle of the trailer outer shell	Drag is reduced	By varying the angle of the trailer outer shell i.e., making it into a reverse aero foil shape the air flow can be redirected and drag can be reduced[30].
Rear of the car	Trunk lid kick up	7.1%	By using a trunk lid kick up the drag can be reduced by reducing COANDA flow[31].
Rear of the car	Boat tail	18.8%	The boat tailing technique is effective in reducing the aerodynamic drag of the automobile, aero foil profile give best overall performance and helps reducing drag[32].
Front and rear	Front and rear spoiler	-0.039	Using front and rear spoilers, help reducing the drag by redirecting the air flow[33].
Rear of the car	Spoiler	3.3%	The rear spoiler helps in diverting the air flow which reduces drag[35].
Vehicle underbody and rear end	Lateral tapering of the rear end and spats	Drag is reduced	The lateral tapering of the rear end and the introduction of spats near the wheels diverts the air flow which intern reduces the drag[36].
Front underbody	Engine bay packaging, redistribution of the cooling air flow exit	Drag is reduced	The change in engine bay packaging, redistributing the cooling air flow, the air flow along the underbody can be reduced, by which drag can be reduced[34].
Underbody	Covering the underbody and crating cavities such that air flows by	10%	By creating cavities in the underbody cover plate the air flow can be diverted which can intern reduce the drag[37].

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