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Recent Trends inAerodynamic Performance Developments of Automobile Vehicles: A Review

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Abstract:*Today aerodynamics of automobile engineering plays a vital in both industry and as well as in research labs. The performance of any automobile vehicle purely depends on its internal and external aerodynamics. To accomplish better performance in the field of automobile engines all the aerodynamics factors must satisfy the design requirements. This review article emphasis more on two broad categories one is heavy good vehicles and second one is lighter vehicles. Both the classification required different aerodynamic shapes and design requirement. Therefore, further this article focuses into more on reduction of drag on vehicle, vehicle aerodynamic instabilities and its possible solutions, design optimization of vehicles which involve finding out the areas that need improvement in the existing designs and looking at some new concept designs. Further to the upcoming researchers this paper also helps in providing the information on recent trends in aerodynamic performance developments of automobile vehicles.*

Keywords: *Aerodynamics, Automobiles, Road vehicles, Drag reduction, Instability***.**

INTRODUCTION

Due to the non-streamline body shape of heavy vehicles, aerodynamicdragislargercomparedtosmallervehicles;hencereductionofaerodynamic drag on commercial vehicles is to be achieved to increasefuel efficiency [1]. The aerodynamic drag generated from the under-bodyflow of a heavy vehicle also has to be studied in order to reduce the totaldrag on the vehicle [2].The fuel expenses are of a concern for the heavyvehicles [3].The commercial vehicles (heavy vehicles) do not undergochangesindesignasfrequentasthelightmotorvehiclesdohencedevelopment of add-on parts has to be done [4].The use of aerodynamicdeflectorontruckscanimprovedragreduction[5].Truckheaddesignwastaken in to consideration to cause a reduction in aerodynamic resistanceand reduce the fuel consumption, since 60% of fuel consumption occursbecause of overcoming the aerodynamic drag at 80km/h [6]. The patternofflowgoingdownstreamoftherearofatractor-trailermodelaffectedbythe placement of the vane type vortex generator (VG) has been studied toseeitaffectthedrag[7][8][9].Theconvoyrollingoftruckshasasignificant effect on aerodynamic resistances; the study has been made tosee the effects of convoy rolling of truck by considering the distancebetween the trucks [10]. When it comes to light vehicles (cars), the dragcanbereducedinseveralways:Bytheusageofarearspoilertheaerodynamic drag on a hatchback model is reduced in order to obtainhigher fuel economy and streamlined drag execution [11][12][13]. Theattack angle of the rear wing of a car place and important role in dragreduction [14][15]. The effects of under body, front and rear wings of anopen wheel race car have been studied to generate down-force withoutincreasingitsaerodynamicdrag[16].theeffectsofdiffusersonproductionof drag was studied [17]. The effects of removing and adding individualparts are observed with respect to drag and down-force [18]. The effectsofwheelsonanopenwheelracecarareobservedwithrespecttoproduction of drag and lift [19]. The effects of side mirrors are studied toobservethehindrancecausedbyit[20].Carshaveaerodynamicallyevolved to produce less CD(up to 0.3) compared to the older cars. Forfurtherreductionofdrag,thedragcausedbytheflowthroughengineroom has to be reduced [21]. Air jet wheel deflector framework waseffectivelyacquaintedwithdecreasevehiclestreamlineddrag[22].Grooved tires and slick tires were distinguished as far as drag coefficientaswellaspressure conveyanceisconcerned[23].For the safety of vehicles and its passengers the instability caused due totheactionofwindistobestudied.Inheavyvehiclesthereisamajorsafetyissue concerned with rollover, which is mainly caused due to crosswinds[24].Theaerodynamicloadsactingonthevehiclewhichisaffectedbythesurroundinginfrastructurelikeflatg round,embankment,singleanddouble viaduct for upward and downward wind and for a trailed unit, hasbeen studied, because the surrounding contributes to the instability of thevehicle[21].Themovingvehicleprocedurewassetuptoseetheeffectsofcrosswindonaheavyvehicle[22].Forcarsthe usageofarearspoilerhelpin reducing turbulence at the rear and increases down-force [11][12].Race car deceleration is also as important as acceleration because of theneed for better handling around the corners, the braking ability of the carcanbeimprovedusingtherearwinganddragformedwhilesteering[14].TheF1carrearwingneedstogenerateenoughd ownforcewhenenteringacornerwithouthavingasignificantincreaseinaerodynamicdragtokeepthe car stable [15]. The effects of under body, front and rear wings of anopen wheel race car on generation of down force without increasing itsaerodynamicdragwerestudied[16].Thewakeareabehindthecarcausesapositiveliftcausinginstability[17].Eachpart andeachchangewillaffectthe drag and down force [18]. The coefficient of lift is affected by thewheels of the race car [19]. The streamlined qualities impact the aspectsof fuel economy and the guiding dependability of a fast moving vehicle[23].whenthediffuserpointbuilds,theunder-bodystreamandparticularlythewakechangeextraordinarilyandtheweightchangecorrespondingly [26]. At a specific height of spoiler, the attack angle forwindimpacthasaneffectonthedragandliftvalue[27].Arelativeinvestigation of the streamlined attributes was made for the body of aFormulaSAEracecarutilizingFLUENTbetweenthestatesofbeingwithout the wing bundle and being with the wing bundle under variousangleofattack[28].Atwo-dimensionalCFDevaluationhasbeenperformedontheairfoilprofiles ofthefrontwingwithandwithoutgroundimpactandbackwings(detached)ofaFormulaMazdaracecarfordifferentattack angles[29].In order to find of the issues in the current designs of the vehicles, theoryrevealing that a mean drag reduction can be achieved by manipulatingwake flow fluctuations was presented [30]. Some quantitative data areprovided to study the flow around the articulated Lorries since there is alack of quantitative data [31]. The effects on the body of a vehicle whilecornering had been studied to improve its aerodynamic characteristics[32]. To find out the area which needs the most attention while designingto reduce the drag on a vehicle is studied using a 2 man bobsleigh [33].UsingdifferentLES(Largeeddysimulations)modelslargescaleturbulentflow structures are shown [34]. Due to increase in global warming, thedesigners are required to design vehicles in such a way that aerodynamicdrag isreduced and hencethere will befewer emissions.Byusing aboxfishdesign,thevehicleswillalsotakeinspirationfromthedesignsthathavebeeninthenatureforsomanyyears(bio-mimicry)[35].Theimpactof a car's tail on its streamlined execution has enabled the designer toproposeanewdesignforthetail[36].Aprototypecarcalled“HorasMesinUSU” was designed with a goal to achieve the best aerodynamic qualities[37]. The change in drag after the expansion of wind screen was shown[38].Thispapercontainsareviewonrecenttrendsinaerodynamicperformance developments of automobiles; the vehicles studied in thispaper are heavy goods vehicles and light vehicles which are cars. Thepaperisdivided intothreemainkeyareas:a)Reductionofdrag,b)Instabilitycausedduetotheaerodynamiceffects,andc)Designoptimizat ion.

REDUCTIONOFDRAG

Inheavyvehicles

A scale model of a truck was used in a wind tunnel to determine thereductionofdragwhendifferentexternalattachmentswereused.Aerodynamic drag (D) is dependent on the frontal area projected (A),coefficient of drag CD, speed of vehicle V and density of air ρ. The formulais give as: $D = 1/2\ (C_D \rho V^2 A)$. Tests were conducted with different windspeeds and different yawn angles, the sensor measured all 3 forces (drag,lift and side forces) and 3 moments (yaw, pitch and roll) simultaneously.The general range of CD is 0.5 to 0.9, the baseline model has the most CDand the model with side skirts, front skirts and the gap between tractorunitandtrailerunitfilled,hadthelowestCD.Theauthorsconsideredthesemethods by looking at papers like [39]–[41]. The experiments conductedshowsthat,amaximumof26%reductionindragcanbeachievedbyusingexternalattachments[1].Theaerodyn amicdraggeneratedfromtheunder-body flow of a heavy vehicle was studied using wind tunnel andCFD methods. The obtained values were compared with Ahmed body[42].details regarding streamline flow around vehicles can be found in[43]. A 15-ton truck and 40 foot trailer were the two models used fortesting.Amodelfittedwithnormalsideskirtsisreferredtoasthestandard, different types of flaps at different angles and a new type ofdesign of side skirt with additional inclined flap panels to smoothen theunder body flow are studied. For the models without skirts, both modelsshowed uniform drag coefficient. For the model with the flap inclination,at 45degree there was max drag reduction that is 5.3% and 4.7% for 15-tontruckand40foottrailerrespectivelycomparedtothenormalskirting.The skirting with inner panel folded, at an angle of 60 degree, the dragreduction was huge compared to the models without a skirt that is 5.1%and5.0%respectively.FromLESitisfoundthatdragreductionoftheflap-type side skirt is 5.4%, it almost is in agreementwiththeexperimentalvalueobtainedfromwindtunnel[2].Toimprovethefuelefficiencyof the truck three methods were studied: energy management, adaptiveaerodynamicsandHumanMachineInterface(HMI).Theauthorhasreferred papers such as [44], [45]. The truck used here is a long haultractorattachedtoasemi-trailer,theenginepresentismodifiedandfittedwith number of electrically controlled actuators, like radiator shutter,electrical fans, electrical water pump, additional generator, controllablethermostat and electrohydraulic power steering servo. The truck is alsofitted with controllable aerodynamic devices that are involved with itsaerodynamicsandfuelconsumption(FC).Thetotalfuelconsumptionwasless than that of a normal truck after with the usage of the combinedsystem. The CFD tests show that fuel saving can be improved up to 0.3-1.5% by using side deflectors. Controllable radiator shutter gives 0.3%and a controllable roof deflector gives 0–2% potential gain [3]. To studytheeffectsofdifferentshapesofflapsattachedatthereartopofthevehiclethatcontributestothedragreductionwithouttheneedofnewdesign,theexperimentwasdone.Asimilarexperimentwasdonebeendone[46].ThestudieswereconductedwithrespecttoAhmedbody[47].TheCFDanalyseswereconducted inStarCCM+.Theflapsusedwerehaving samewidthasthetruckbodybutweretestedfordifferentlengthsandmountingangles,theflapweretestedwithsamelengthsandsurfaceareasrespectively for all the different shaped flaps. Even perforated flaps weretested with different perforation diameters. The flap shapes used wereElliptic, Rectangular and Triangular. The angle of 50º was found out to bethebestangleofmountfortheflap.Theellipticalshapedflaphadthemostdrag reduction compared to the rectangular and triangular shaped flapsfor all different lengths tried out. Maximum drag reduction of 11.1% wasfound using an elliptical flap over the baseline model. Even in the case ofperforatedflapsellipticalflapsgave the mostdragreduction,for thebiggestperforationdiameterused[4].

Hence the vehicles with most of the surface area covered can have lessaerodynamic drag and will be more fuel efficient, which will also reduceemissions[1].InLESflowstructuresuggestthat,dragthroughthecombined effects of reduced vertical activities, stream wise momentumloss,turbulentkineticenergy,andpressuredifferencebetweentheupstream and downstream of rear wheels are reduced by flap-type sideskirt, however this paper only studied the under-body flow and its dragreduction [2]. The CFD tests show that fuel saving can be improved byusing side deflectors, controllable radiator shutter and a controllable roofdeflector[3].Thenewellipticaldesignofrearflapsperformedbetterthanthe standard designs that are commercially in use as of now, the ellipticalflapresultedinsymmetricpressuredistributioninthewakewhichinturnreduces the drag [4]. These papers studied the effect of drag reduction byusingdifferentkindsofsideskirts,flapsanddifferentexternalattachmentsthatinvolvedcompletelycoveringupthespacethatareopenonaheavygoodsvehicle.Outofthesestudiesthemaximumdragreductionwasseenin[1],becausetheyhadcoveredupthemaximumareawhere there were gapson the vehicle, but the practicality of covering upmostof thegapsisyettobeseen.In Asian subcontinent especially in Bangladesh and Pakistan, most of thetruck deflectors are not designed to be aerodynamically efficient but aremadeonlyfortheaestheticappeal.Theauthorsstudiedthedraggenerated by these deflectors and compared it to a baseline model, andalsocompareditttoanaerodynamicallyefficientdeflector.Theauthorhadconsideredsometestslike[48]toconductthisexperiment.Thestreamlineddeflectorproduced13%lessdragcomparedtobaselinemodel. Whereas the traditional deflectors from Bangladesh showed anincrease in drag up to 33% and the Pakistani version increased it up to56% [5]. Three models of trucks were tested in the study by using solidworksflowsimulation:1)truckwithoutfairing2)truckwithanolddesignof fairing 3) truck with a new design of fairing (old design fairing located500mm forward). The models were taken with reference to some papersincluding[49],[50].Theexperimenttriedtodeterminetheoptimallocation of the fairing on top of the truck. The pressure contours showedthatthemodel3hadtheleastpressureactingonitscarriage,thepressureon glass window of model 3 was reduced by 75.45Pa as compared tomodel 1. The pressure on the hood decreased by 5.53Pa for model 2compared to model 1, while it increased by 1.94Pa for model 3. Fromvelocity contours it was seen that model 3 almost completely streamlinesthe flow near the separation of tractor and trailer part when compared tomodel 1 and model 2. The model 3 also had the least aerodynamic forceandcoefficientof dragactingonitas comparedtomodel1and2[6].

Theexperimentconcludedthatbyemployinganaerodynamicallydesigned deflector the drag can be reduced and fuel can be saved [5]. Itwasconcludedthatiftheentirevehiclestructureisinastreamlinedshapethe aerodynamic resistance will reduce, and the bestlocation for theplacement of the fairing was determined to be the new position withcomparisontoothermodels[6].Henceitisshownthattheuseofaerodynamic front fairings or deflectors could easily reduce aerodynamicdragonthevehicle,butlackofknowledgeaboutaerodynamicsmayresultin increase of drag. There are other methods that can reduce the drag ofthevehicle liketheusageofvortexgenerators.The authors have studied the pattern of flow downstream of the rear of a1:20scaletractortrailermodelaffectedbytheplacementofthevanetypevortexgenerator(VG).Thestudywasdoneusingcounterrotatingbackward facing vane type VG of two sizes VG1 and VG2 respectively andwere placed in two locations on top of the trailer, one near the front andother near the end. For the experiment to be proceeded in this way theauthor has referred to papers such as [51], [52]. The gap between tractorandtrailerwasminimal.Theexperimentsweredoneusingaclosedloop low speed wind tunnel and the model was placed on a false floor.Fromthesmokevisualizationtestsitwasclearthatforallthearrangements the flow separation was obtained downstream in the rearend of the trailer. The flow was highly downward in the case of the vanewhich was bigger (VG2) and placed near the front of the trailer. Whencompared to a baseline model the models having VG could decrease therecirculationareabehindthetrailer,itwasbetterforVG2.Itwasfoundthat when the VG was placed in the front area of t he trailer the distanceand time available for the mixing of flow between the boundary layer andfree-streamincreases.Thusattherearendoftrailerthedownstreamflowpattern is changed. The size of the recirculating region was reduced formodels with VG when compared to the baseline models. When VG2 wasinstalledinthefront12.9%reductionofwakevortexwasfound,butwhenit was placed in the rear reduction was found to be only 5.8%[7]. Aninvestigationofthelikelihoodtoutilizeplasmavortexgeneratoractuatorsfor drag decrease on trucks had been brought out by using wind tunnelwheretheactuatorshavebeensetontheA-pillarwithreferencetoworkssuchas[53],[54].Theprincipleobjectivewastoperceivehowtheactuators can be utilized to diminish the drag when the truck goes with ayaw point with regard to the relative breeze speed. The wind tunnel testsdemonstrate that drag decrease is conceivable and at a 9 degree angle adecrease of up to 20% in drag can be accomplished. As far as the controlcoefficientitdemonstratesthatlikewiseanetdragdecreaseisconceivable, that is, in the event that the penalty control utilization of theactuators are considered [8]. The drag on the tractor trailer model wasdecreased using two types of vortex generators, which are air tabs andvortex generators commonly used on aircraft wings. Two models weretested a single vehicle and two vehicle with convoy rolling distance on ahighway.Thevortexgenerators wereplaced on topand sidesof thetrailing edge. With the use of air tabs a drag reduction of 1.29% wasobtained for single vehicle on a highway and a net reduction of drag of4.98% was obtained for both the vehicles was obtained when two vehiclewith a convoy distance was simulated. The aircraft VG increased the dragonthevehicleby0.65%and0.105%forsingleandtwovehiclesinconvoyrespectively[9].

Fromthetwomethodsuseditwasclearthatboththewakeregionandtheflow reversal strength could be reduced using the bigger vane vortexgenerator at thefront of the trailerunit witha square back [7]. Theexaminationin[8]shouldhavebeentakenwithsomealertastheReynolds number in the wind tunnel is lesser than for full scale, theoutcomes are empowering. Work needs to be done with respect to actualsize model and also different designs for the actuators [8]. The expansionin drag with the expansion of aircraft vortex generators could be creditedto the stature of the vortex generators off the trailer's surface. They couldhave broadened too far into the limit layer, refuting the advantage ofprompting vortices noticeable all around running off the trailer's surface.Thedragincrementcouldlikewisebebecauseofspacebetweenthevehiclesinconvoy[9].Hencethevanetypevortexshowedbetterreductionofdragwhenplacedinthefrontsideofthetrailer,comparedtoother VGsused.

Theconvoyrollingoftruckshasasignificanteffectonaerodynamicresistance, the authors have studied the effects of convoy rolling of truckby considering the distance between the trucks. The analysis was doneusingANSYS,fourtruckmodelswereplacedbehindeachotheratadistance of 3 meters as it is considered as the safe distance in real trafficscenario. From vector analysis plotted at y=0 plane determined that thefirst truck had the highest drag compared to the trucks that followed, butthewake structurebetweenthefirstandsecondtruck wasdifferentcompared to the other trucks, showing that the second truck had moreadvantage compared to the others. The entire convoy is also covered in astreamofairthusreducingdrag.Fromstreamlineanalysisitcouldbeseenthatwakewassimilarforalltruckswhichcouldbeimprovedusingexternal attachments that improve the aerodynamic properties. It wasalso found that the turbulence on the second truck was higher comparedto the rest. From the plot of surface pressure, it was clear that the firsttruck had the highest pressure acting on its frontal area, the second onehad a 75% reduction in pressure and the following trucks had furtherreductioninpressurebutwerenotverysignificant.Byconductinganalysis on the pressure borders, it was found out that the areas in thefrontofthecabandbacksideofthecabneedsimprovement.Thedisadvantage here could be that there might not be enough direct airavailable(forthetruckthatfollows)toentertheheatexchangerhencetheheat exchanger system might have to be optimised, but there is reductionof aerodynamic resistance as well, which will cause the engine to workmoreeasily[10].Theexperimentisconcludedwithresultsthatshowthatthereissignificantreductionofaerodynamicreductionfortrucksinconvoy,exceptfortheleadingtruck[10].Additionalworkcanbedonetodeterminetheperfectconvoydistanceandtheproperheightoftheaircraftvortex generator and the size of these vortex generatorusedshouldbeproperly determined[9].

Inlightvehicles

Bytheusageofarearspoilertheaerodynamicdragonahatchbackmodelisreducedinordertoobtainhigherfueleconomy.Air-flowatrearwascomparedto[55].Thecaristestedwithandwithoutarearspoilerandtheresults are discussed. The test was conducted in a subsonic suction typewind tunnel. The scaled model of the car is placed in the wind tunnel. Itwasfoundthatthecarwithspoilerhadlowerpressurevariationcompared to car without spoiler. It was alsofound that the car withspoiler had lesser drag force. The coefficient of pressurewill be veryeffective for car with spoiler at high speeds [11]. The RANS-based CFDre-enactments have been conveyed up to research the impact of backrooftopspoileronthestreamlineddragexecutionofanimprovedhatchback. The outcomes demonstrate that the basic strip-type spoilercould have a valuable impact from 0° to 5° angle of pitch the results werecomparedtoAhmedbody[56].Afterthisrange,theCdisfoundtoincrementwithbiggerangleofpitch.Thespoilerdependsontwoprimarysystems to lessen streamlined drag: 1) by keeping the wind current fromquickening at the main edge of the inclination segment, 2) by keeping thearrangement of longitudinal vortices from forming, along the edge of theinclination area. The present outcomes were gotten from stationary re-enactments in which the movement of the vehicle body has notbeenconsidered. Movement of vehicle body is normal in real world scenario,and could change the tendency point of the spoiler when the movementmodeisofpitching[12].Theauthortookintoconsiderationspaperssuchas [57],[58].Using wind tunnel experimentation the aerodynamic characteristics of arace car wing is tested and later the values obtained are compared withthe values obtain from CFD simulation. Some values were obtained inexperiments such as [59], [60]. All the 3 momentum and all 3 forces arefoundout.Thepressureanddragonwingisfoundoutinwindtunnelandcompared with CFD analysis found with STAR-CCM the average relativeerror is found to be 4%. When the sideslip angle is fixed, there is nocorrelation among aerodynamic force and moment coefficient and speed.When the speed is fixed, with the increase of sideslip angle, aerodynamicforceandtorque coefficientsshowedacertainchangeregulation[13].

For a race car deceleration is also as important as acceleration because ofthe need for better handling around the corners, the braking ability of thecar can be improved using the rear wing and drag formed while steering.NITK Racing Formula Student Car used a mechanical actuator to convertthe translator motion of brake pedal to rotatory motion of the aerofoilbladeonthewing.Variousattackangleswereusedtofindthebestmedication for the rear wing aerofoil. The differencebetween coefficientof drag of the initial aerofoil design and modified design were observed.$CD=2\sin^2\alpha$usingthisitwasfoundthatsufficientdragwasobtainedwhilevarying the angle α from 30 to 80 degree, the maximum drag can beestimatedusing$C_{D,max}=(1.994-5.4375)y/c$,whereyistheaerofoilthicknessmeasured attheleadingedgewhenx/cis0.0125,x isthedistance from the leading edge on the chord line and c is the chord length[14]. Forthisexperimentsomereferenceswerefrom[61].Theauthorsuseda2DmodelinFLUENTtoinvestigateairflowaroundtheF1wingusingk-ε,k-ωandk-kl-ωmodels.Aspeed of43m/swasusedinorder as it is the average speed at which an F1 car enters the corners. Thewingsweremadeofmainplaneandflapwing.Therearwinggenerateshighdown-forceiftheangleofattackishigh,whichalsoincreasesthedragonaerofoil.12modelsincluding 3 different thicknessesfortheflap wing,withtheclosingat10mmandopeningat50mmwhenDragreductionsystem(DRS)wasactivatedwasconsiderwithbigandshortflapwings.InDRSflapwingopensandcloseswhenthedriveractivatesit.Asthereislackofexperimentaldataontherearwingof F1carsonlysingleaerofoilwasconsideredforvalidation.Abookproducedbydirectorof NASAwasusedtocomparethenumericaldataobtainedwiththeirexperimentaldata.Usingthe3 turbulence modelsthetestwas conductedfor attackangleof0^o.Itwasobservedthatk-kl-ωwasmostaccurateforpredictionofseparationbubbleformation,growthandreattachments;henceitwasusedforallcases.Itwasfoundoutthatthedragproducedbytherearwingconsisting of main and flap wing, decreases with increase of the thicknessofaerofoil.Fromtheresults,thebigflapsusedinthewingproducedgreaterdown-forcewith comparisonto small flaps butwhenDRSwasusedsmallflapshavethetendencyofincreasingthespeedofthecarbyreducingdragforce.Henceitwasconcludedthatshortflapsarebetterfora F1 car in a circuit where there are higher number of straight lines [15].Theauthorsstudiedtheeffectsofunderbody,frontandrearwingsofanopen wheel racecaron generation of down-force withoutincreasing itsaerodynamicdrag.Thesteadyviscousflow isassumed andReynolds-averaged-Navier-Stokesequationsalongwiththestandard SST(k-ω)turbulencemodelareusedfor simulation.Fourmodelswereused forcomputationalsimulations:A)carwithaflatunder-body,B)carequippedwithreardiffuserintheendoftheunder-body,C)isequippedwithdiffuserattheendofunder-body,andfrontandrearwingsmadeof2elements D) is equipped with diffuser at the end of under-body, and frontandrearwingsmadeof3elements.Thediffuseremployedcreatesfavourable down-force without affecting drag, while the front and rearwingsproducedown-forcewithincreaseindrag.Theeffectsofdragweresimilar for both C and D, which shows that for a given angle of incidenceand same overall chord length, the number of elements, doesnot make asignificanteffect.Withrespecttothelift-to-dragratioCandDarepreferred,butmodelDispreferredoverCbecause3elementsareoflesservolumecomparedto2elementsand henceweighsless.AfterthemodelDwas selected as the favourable model for an open wheel race car the flowaroundtherearwingisstudiedusingwooltuftsandcomputationalanalysis,itisfoundthatboththetechniquesagreewitheachother[16][62].Using the flow around the car by employing CFD analysis (Ansys 14.5) acarofproductionmodelwasstudied,thecarwasalsostudiedwithdiffusersatdifferentanglesandthemodelwhichwasoptimumwasselected. The accuracy of the CFD solver was found by testing a test caseAhmed body, the CD values agreed with the one found in the wind tunneltest. After the test the car model employed was found to have the samevalues of CD and CL. The car model then was tested with an addition ofreardiffusersatdifferentangles.Afterthetestwascompletedtheangleof8^{o} was found to be the best angle, because it decreased the CL (-0.01968)withanegligibleincreaseinCD(+0.0019).Foranglesgreaterthan8^{o}eventhoughCLdecreasedtheCDvalues alsosignificantlyincreased[17].

ImprovementoftheformulaSAEfirstprototyperacecarwhichbelongstothe University of Perugia was done using wind tunnel and CFD analysis.The streamline characteristics of a formula SAE car can be referred from[63],[64].Thefirstphaseofthestudywaslimitedtoonlythenosepartofthe car, the purpose of this phase is to find out if the drag in experimentalandnumericalanalysisisagreewitheachother.Thesecondphasecomparestwoentireracecarsonlynumerically;thetwocarsusedareRB11.1_aandRB11.1_B. The wind tunnel at the University of Perugia is a closed loopconfiguration. A full scale vehicle nose was used, test runs were of 75seceachand wereconducted using3 setups:rising speedramp,regime,decreasing speed ramp. The CFD analysis was conducted in study stateusing incompressible model since k-ω is one of the best turbulent modelit is used here. The wind tunnel value of coefficient of drag obtained forthephaseoneis0.46andCFDvalueis0.43.Forphasetwoaftercomparingthenumerical analysis by removing and adding individualparts, it isobserved that each part and each change will affect the drag and downforce[18].ARTeC'sEMo-C car is a formula type car with fenders on the rear tyres,the drag coefficient and airflow around the body is found out using CFDand wind tunnel experiments. The EMo-C car is a car with blended wheelbody concept meaning it is a combination of formula type cars and urbancars,butithasaverysmallfrontalfaciacomparedtourbancars,itisacarbuiltforaraceofmaximumfuelefficiency,henceevenlowspeedaerodynamicsisconsidered.FortheCFDanalysisFLUENTisusedatspeedof13.9m/s.AcarmodeliscreatedinCATIAandpre-processedfordiscretization of control volume, using GAMBIT. Invisid flow is used at 1atmospheric pressure, the drag coefficient without tire is 0.312 and withtireis0.42.Forwindtunnelexperimenta1/10thscalemodelisusedat10-30 m/s, the wind tunnel is equipped with 3 component balance, the dragcoefficientwasfoundtobe0.48.ThevalueobtainedfromCFDis lessthanthe wind tunnel value this is because CFD did not take in to considerationthe skin friction. 25.7 % of profile drag coefficient is due to the tires,withouttirestherewillbereductionindragcoefficient.Aerodynamicdragcomes into consideration for not more than 20% of overall power of theenginewhileatanaveragespeedof40kmph[19].Theassessmentofstreamlinedstreamconsequencesforsidemirrorshapeforanormalcarutilizing ANSYSFluentCFDprogrammingisstudied. From the pressure coefficient examination on side view mirroroutlines results are assessed to break down the unstable powers thatbecomethereasonsforthevacillations tosurfaceofthemirrorandpicture obscuring. The vacillation additionally causes drag powers thatexpandthegeneraldragcoefficient,withapresumptionofbringingabouthigher fuel utilization and exhaust discharge. Three types of side viewmirrorsconfigurationwereresearchedwithtwospeedsof17m/sand33m/s. Type 1 was dependent on a semi-circle shape while type 2 wasdependent on asharp end withtriangular shape and thetype 3 wasfinishedbyconsolidatingrectangularshapewithtriangularedges.Resultsdemonstratethatthehalf-circleconfigurationdemonstratestobethebesttypewiththeleastchangeindragandpressurecoefficient [20].

Over the years passenger cars have aerodynamically evolved to produceless CD(up to 0.3) compared to the older cars. For further reduction ofdrag,theinnerflowdragofcarsisconsidered.Thedragwithintheengineroom contributes to about 10% of total aerodynamic drag. The car wastested on the large-scale low-speed wind tunnel of Tokai University withmoving belt ground for 6 types of inlet grill openings including a noopening grill arranged in 12 different positions. The engine was loaded inlengthwiseandwidthwise,itwasalsotested withandwithouttheplacementofaradiator,henceatotal of48flowpatternsweretested.Thetests concluded that with the increase in inlet opening size the drag andthe front lift increased but the rear lift decreased for the models withoutradiators.Formodelequippedwithradiatorthedragincreaseswithincrease of height of inlet but the effects of position of opening is minute,front lift increases with decrease in inlet opening height, the rear liftbecomes less considerable. Hence the drag and lift depends on the heightofinletopening,butthedragisalsomajorlyaffectedbyenginearrangementandalsothepositioningoftheinlet[21].

Airjetwheeldeflector framework was effectively acquainted with decrease vehiclestreamlined drag. The framework is situated before the haggle air flyopposite to the free stream bearing in understanding with vehicle drivingvelocity.Thisairstreamactslikeanairshadewhichdecreasesthestreamlined drag by avoiding the free stream far from the tire. It wasillustratedthatastheairflyspeedexpands,thedevelopmentofstagnationweight was deferred at the tire surface which results in the tire dragdecrease.Moreover,itwasfoundthatmassstreamratetothewheelhouseis altogether lessened which results in drag decrease as the air fly speedincrements. A parametric report for the air fly diverter framework bychangingairflyspeeduncoveredthatdragdecreaseof6.4%wasaccomplished when the fly speed was indistinguishable to vehicle drivingrate. This framework can be utilized not just for the drag decrease yet inadditionimprovingbrakecoolingexecutionbytiltingtheimpingjetheadingtothebrakecaliper[22].Themostvitalcontrastsbetweenstreamaround the grooved tires and slick tires were distinguished as far as dragcoefficientaswellasweightconveyance.Exactinvestigationoftwomethodologiesutilizedforwheelreproductionunmistakablydemonstrated that the utilization of Multiple Reference Frame displayfundamentally enhances the exactness of numerical model. Distinction indragcoefficientbetweennumericalexaminationandanalysisforslicktirecanbeassociatedwithweightdropclosetothe regionofcontactbetweenthegrounds.Samepropensitycanbewatchedfortirewithnotches,anyway flying impact related with slick tire is in charge of greater weightdrop and as a ramification for greater profile opposition. Those wonderswereclarifiedbyInstituteofTurbomachineryatLodzUniversityofTechnologyinparticipationwithPSAPeugeotCitroendependentonPeugeot207body.ConsequencesofnumericalexaminationswereconfirmedinPSAwindtunnel [23].In cars the drag can be reduced using several external add-on elementssuch as spoilers, aerodynamic shaped mirrors, diffusers and so on. Theusageofarearspoilerhelpinreducingturbulenceattherearandincreases down-force [11]–[16]. The attackangle is a very importantfactor as after certain angles they can increase drag instead of decreasingit as seen above. Spoilers with actuations can give the best result as it cancreateexcessdown-forceonlywhenrequired[14],[15].Whereasdiffusers are better used for lift management rather than decreasing drag[17]. Table.1comparesdifferentmethodsofdragreduction.

TABLE1. Comparingthedifferentmethodsusedbydifferentpaperstoreduceaerodynamicdrag

Vehicle type	**Description**	**Advantages**	**Limitations**	**Remarks**
semi-trailer truck[1][3]	Use of side-skirts and different fairings	Drag was reduced	Complex nature of design	The real size model has to be tested
Truck-trailer [2][7][9]	Different side skirts. Different types of VGs	Maximum drag reduction for 45o inclined skirt. VG reduces drag.	ground clearance is reduced	The VG position and design must accurate
truck[4]–[6]	Differenttypesofflapsandfairingsaretested	Elliptical flaps andaerodynamic deflectorsplaced forward,reduced drag	Testsdonewerelimited	Dragreductionispossible byusingthesemethods
Hatchback car[11][12]	Dragreductionbyrearspoiler	Thespoiler reduceddrag	Properanglemustbemaintainedforthespoiler	Spoilerscanbothcreate andreducedrag
Racecar[13]–[19]	characteristicsofthewing,diffuserandunderbody weretested	Modelequipped withfront and rear wing anddiffuserhadthebestresult	angleofattackmustbevariedtoadopttothesituation	Actuatedwingsadapttorequiredsituations
Passenger car[20][21]	Designofsideviewmirrorsandengine roomflow	Semi-circleshapemirrorwerebest.	Testswerelimited.10%dragcanbefromengineroom	Moremirrorshapesandenginelayoutscanbetested
truck[4]–[6]	Differenttypesofflapsandfairingsaretested	Elliptical flaps andaerodynamic deflectorsplaced forward,reduced	Testsdonewerelimited	Dragreductionispossible byusingthesemethods

		drag		

INSTABILTYCAUSEDDUETOAERODYNAMICEFFECTS

Inheavyvehicles

When it comes to heavy vehicles crosswind which causes rollover is a bigrisktothepassengersinit[24],[25].Withrespecttoaheavyvehicleinflatgroundscenario,athigheryawanglestheeffect soflowandmeanturbulentconditions weremadeclear.The simulated vertical wind speeds control the moment of roll and lateralforces. At the windward roof edge the vertical component of the flow ismainlyaffectedatitsdetachmentpoint,whichmovesupwardwhensuction over the roof toincreases, which leads to bigger upward directedverticalforce.Detailregardingcrosswindeffectcanbefoundin[65]–[69].The trends of lateral force and roll moment admittance functions arefoundtobesimilar,thatiswiththeincreaseofnon-dimensionalfrequencyfrom0-∞theydecreasedfrom1–0.Theadmittancefunctionwithrespectto vertical force is 1 at 0 non dimensional frequency and maximum withunitnondimensionalfrequency.Verticalforceisindependentofthepressureonthelateralsurfacebutthemaininfluenceforitisthepressuredistribution underneath and on the top of the vehicle. With respect toheavy vehicle moving in ascenario other than flat ground, which areembankment, single and double viaduct for upward and downward windandfortractortrailerwithatrailedunit,forallyawangles,theflatgroundis having the least effect of rollover. Highest risk of rollover was found tobe for single viaduct at larger yaw angles ($\alpha>50^o$) and at small yaw anglesforembankmentanddoubleviaductscenarios.Onviaductandembankment,thelateralaerodynamicforceactingonthevehicledecreases form upward to downward wind flow position as well as rollmoment, for high yaw angle. A considerable difference was found in yawmoment of viaduct and embankment scenarios, the amplitude of bothremainssamebutareinoppositesigns[24].Themovingvehicleprocedurewassetupandapprovedutilizingtheexperimentoftwoprismsinrelativemovementundercrosswindactivityandcontrastingthenumerical wind tunnel results and the trial ones of a comparable caseintroduced in the writing. Asymmetry in the side power and yaw momentvarietynearthepinnacleisavailableduetothenon-symmetricalgeometry of the genuine truck. The horizontal speedup of the crosswindinitiated by the pinnacle corners results in the lateral force and the yawmoment serving as the vehicle methodologies and leaves the pinnaclewake, while a 30% decrease in the side force happens when the vehicle isamidstthewake[25].After comparing the different types of trailers, the smooth surface of tankwas having lower lateral forces. The trailers with larger areas on sides onwhich the wind acts the most had higher risk of rollover, they were foundto have very high points of force acting on it. The yaw moment is mainlyaffected by the length of the vehicle [24]. The lateral force admittancefunctionismainlyinfluencedbythesideareaofthevehicleonwhichwindis acting [24], [25]. If the side area on which the wind is acting on is largetheamplitudesofthelateralforceadmittancefunctionwillbesmaller[24].

Inlightvehicles

Theusageofarearspoileronahatchbackcarhelpedinreducingturbulence at the rear and increases down-force [11]. The RANS-basedCFDre-enactmentshavebeenconveyeduptoresearchtheimpactofbackrooftopspoileronthestreamlineddragexecutionofanimprovedhatchbackshow.Theoutcomesdemonstratethatthebasicstrip-typespoiler could have a valuable impact from 0° to 5° angle of pitch [12]. Therear wing of a formula type race car should produce high down-force forstability around the corners, but it should not increase the drag whengoing inastraightline,thisisachievedbyusing actuators,bestanglefortheaerofoilwheninstraightlinewasdependentonthedesignofthewing,the best angle formaximum stopping force was when thewing wasperpendiculartoflowofwind[14],[15].Theopenwheelracecarequipped with front and rear wings and a diffuser performed much betterthan a car equipped with none of them as well as car with only front orrear wing or diffuser [16]. The car models were tested with an addition ofreardiffusersatdifferentangles.Afterthetestwascompletedtheangleof8^o was found to be the best angle, because it decreased the C_L(-0.01968)with a negligible increase in C_D(+ 0.0019) compared to the car modelwithout a diffuser, for angles greater than $8^o$the C_D values increased. Thewake area behind the car can contribute largely to the positive lift, hencethewakeareabehindthecarwasreducedandtheairwasdirectedupwards,hencereducedliftandincreaseddown-forcewasfoundwiththeemployment of rear diffuser [17]. By removing and adding individualparts,itisobservedthateachpartandeachchangewillaffectthedraganddown force[18].

TABLE2. Comparingthemethodsusedtocontroltheaerodynamicinstability

Vehicletype	Description	Advantages	Limitations	Remarks
Truck[24][25]	Effects of crosswindwhich causesrollover	Smoothwindwardsurfacecanreducethechancesofrollover	Thesurroundingseffecttheforceactingonthe vehicles	vehicledesignhastobeimprovedtoavoidrollover
Hatchback car[11][12]	Usingspoilertocreatedown-force	Angleof0to5degrees createhighdown-force	Iftheattackangleistoohigh itcancreatedrag	Down force should
Racecar[14]–[19],[28],[29]	Thewing,diffuserandunderbody weretested	8ºto16ºdegreeattack angleprovidedenoughdown-force	Furtherincreaseinanglecanalsoincreasedrag.Thetiresproducedlift	Actuated spoiler creates drag whenrequiredandreduces whennotrequired
Passenger car[17][26],[27]	Theeffectsofarediffuserandspoileron airflowwerestudied	Angleof8ºofdiffuser hadsufficientdown-force.Spoiler of12ºinclinationwas ideal	Beyond8ºangleofdiffuser thedragincreases.The12º spoilerincreases CD	The lift can be reduced but it shouldnotincreasethedrag

The lift caused by the tiresweretested and the liftcoefficient without tyre is= -0.053 and with tyre is 0.339 [19]. The under-body backside diffuser is one of critical streamlined extra gadgets. Theimpact of the angle of diffuser was examined with the absence of theseparator and the end plate. The technique for CFD was embraced toconsiderthestreamlinedqualitiesofanimprovedvehiclewithanalternatediffuseredgeindividually.Thediffuserpoint wassetto0°,3°,6°,9.8° and 12° separately. The initial model had a diffuser point set at 9.8°.The results showed that when the diffuser point builds, the under-bodystream and particularly the wake change extraordinarily and the weightchange correspondingly; thus for the car, the aggregate streamlined dragcoefficientsdiminishesfirstandafterthatitincrements,whiletheaggregatestreamlinedliftcoefficientsdiminish[26].Ataspecificheightofspoiler,thespoilerthathaslittlerattackangleforwindimpactgiveshigherdrag value. This is because of the way that with littler attack angle, thespoilerwouldmakelittlerre-flowzonebehindthebacksideofthetravelling vehicle. The wind stream behind the vehicle is diverted by theback spoilers and increments the down force of the vehicle. The spoilerwith inclination of 12 degree demonstrates the most ideal case, howeverit makes 1.56% additional CDthan the spoiler with angle of inclination of4 degree . Least CLis kept up in the model which is fundamental necessityfor better handling of high velocity vehicle [27]. A relative investigation ofthestreamlinedattributeswasmadeforthebodyofaFormulaSAEracecarutilizingFLUENTbetweenthestatesofbeing withoutthewingbundleandbeing with the wing bundle under various angle of attack: 1) Without thewings,thestaticweight of thefrontbody,thefrontpiece of the tiresandthedriver'schestandheadisthemostastounding.Thereareenormous vortexes behind the driver creates a great deal of negativeweight. 2) With the wings, the wings can give huge down-force which canenhance the car’s execution in the Dynamic Events. At the point when theangleofattackofthebackwingis8°,itcansupply65%down-force.Itcangive hypothetical premise and specialized parameter for the streamlineddevelopmentplanningandenhancement ofcars[28].Thefront wingappears to build up a bigger net down-force when stream is re-enactedwith ground impact. The outcomes demonstrate that there is a slightincrement in the CL of around 20% from 0^0 to 12^0 attack angle. Also, thereis a checked diminishing in CLaround 45%, which may demonstrate thatbetween $12^0$and 16^0attack angle there is a potential for a "slow down"conditionwiththeair-foil.Additionally,theCdforthiswingdemonstratesaconsistentincrementtoaroundhalfuntilthe12^0attackangleiscometo,afterwhichtheestimationofthecoefficientesteemturnsouttobemoderately steady [29]. The designs for the air-foil where also taken from[70][71].In cars the instability caused is mainly due to the positive lift created; thiscan be stabilized by creating negative lift (down- force) [11], [12], [14]–[19], [26]–[29]. The down forces can be created by using rear diffusers[16],[17],[26],rearspoilers[11],[12],[14]–[16],[27]–[29],frontspoiler[16],[19],[29].Thetechniquesusedbyracecarscanalsobeimplementedon to thepassengercarsupto acertainextent,butthecostofproductionmayturnouttobeimpractical.Table.2comparesdifferentmethodstocontrolinstability.

DESIGNOPTIMIZATION

Designfeaturesthatrequireimprovement

Todevelopnewdesignstheareasthatneedtobeimprovedontheexistingdesignofthevehicleandmethodssuitableforanalysismustbefoundout.Theoryrevealingthatameandragreductioncanbeachievedbymanipulating wake flow fluctuations was presented. In blunt bluff bodies,duetothebluntrearfacethereiswakebehindthebody,creatingpressuredropcomparedtothefront.Usinglinearfeedbackcontrol,themeanpressureonthebaseofthebodyrequiredtoobtaindragreductionshouldbe increased. To obtain the relationship between mean drag and flowfluctuations a bluff body in a control volume with incompressible flow isconsidered. The use of feedback loop control made the D-shaped bodyachieve better results in terms of achieving better attenuation of basepressurefluctuationandincreasingmeanbasepressure.Thecontrolstrategy is based on body mounted sensing and actuation only and hencecanbeusedonmovingbluffbodies[30].Someideasregardingstreamlineflowaroundheavy vehiclescanbeobtained from [72], [73].TostudytheflowaroundthearticulatedLorriesthereisalackofquantitative data, hence this study tried to investigate and find out somequantitative data. [74], [75] have been referred to get a clearer idea onaerodynamic characteristics of a heavy vehicle. FromSurface oil flowvisualisationitwasobservedthatinfrontofthetractorthereisastagnation zone, and due to the sharp front edge of the trailer there ispresence of small separation bubbles, hence, at the back side of the trailera minimal downwards pointing shear layer and a large counter-clockwiserotating wake vortex had appeared, it concluded that two sides of thearticulated lorry model had symmetrical flow pattern, a huge span wiseflow separation was found at beginning of tractor model, at the rear end apair of counter rotating vortices is found due to a region of low pressurewake.Fromthetwo-componentparticleimagevelocimetrymeasurements we can conclude that a stagnation point is in front of thetractor model, second stagnation point is in the front edge of trailer, aseparation bubble was found in front of the tractor model, large counter-clockwise rotating wake vortex was found at the rear end of the trailer.Theinstantaneousstreamwiseflowpatternsolvedthroughtwocomponent particle image velocimetry measurements tells that there aretwostreamlinevortices formedinthewakeregion[31].Thechangeofaerodynamiceffectsonthebodyofavehiclewhilecorneringwhen compared to it travelling on a straight path was studied using Wall-resolved Large Eddy Simulations, on a Ahmed body with a 25^{o} slant backat the rear top (Ahmed body [47]). The curvature of the path of vehicletraveling through a corner is inversely proportional to the radius. Whenthe radius of the corner was 5L (L is length of the vehicle) there was anincrease in drag coefficient by 19.2% as compared to when travelling in astraight line and for larger radius it decreased. Also for the 5L corneringradius because of the thickness o f the outboard side boundary layer themaximumincreaseintheviscousdragvaluewasby8.3%.Therearfaceofthe body contributes greatly for the increase in drag, due to the change inthewakestructurewhichresultsindecreasedflowoverthesurface.Sincetherewashigherpressure on outboard sideand thepressureon theinboardsidewaslowertherewasanegativesideforceactingtowardsthecentre of rotation. There was an increase in angle of vortex formed in theC-pillar across the slant back face, which caused an increase in verticalextensionof pressuredeficit[32].Theaerodynamicsflowofastandard2manbobsleighisstudiedinawindtunnel experiment using a 50% scale model. The model was first done inCATIA and then a real model was made using high-density polyurethanefoam.ThebobsleighwasplacedintheRMITwindtunnel50mmabovetheground using a special mount, a multi axis force sensor was used. The testwas conducted with varying speed from 30 km/h to130 km/h, with anincrementof10km/hatzeroyawangles.ThedragforceDwasconvertedtocoefficientofdragCDusing:$CD=D/(0.5\rho V^2 A)$andReynoldsnumber$Re=\rho Vl/\mu$.Tounderstandtheflowbehaviouraroundthebobsleightwomethods were used, for high speeds the wool tufts were cut into 40mmpiecesandattachedonsurfaceofbobsleigh,andairflowwasmeasured,forlow wind speeds smoke visualization was conducted. The experimentallyobtainedvalueofCD=0.289withoutthecrew,runnerandcarries;withthecrewitcouldbearound0.314.Flowvisualizationindicatesthatthedesignof the rear bumper is not very effective in reducing CD as compared to thefront noseandthe sidecurvaturedesign[33].

Newconceptdesigns

By using a boxfish design, the vehicles will also take inspiration from thedesignsthathavebeeninthenatureforsomanyyears(bio-mimicry).Overtheyearsthedesignsofcarshavecontinuallyevolvedtoreducethecoefficientofdragduetoair,howeverthereisstillscopeforimprovementsifsomechangesaredone,butthesechangesshouldnotaffectotherperformance parameters such as cooling etc., hence experimental andcomputational methods are used to study the aerodynamics of boxfishdesign. The Ostraciidae fish family have the body geometries which aredesirable to design a vehicle, especially yellow boxfish due to its simplebox geometry. The experiment conducted used RMIT wind tunnel, withclosed return circuit and rectangular cross-section. A Styrofoam model oftheboxfishwasconnectedwitha6componentsensor(JR3).ACADmodelprepared in CATIA was used in CFX (version 14.5). Reynolds numbersensitivitytestandyawnangletestwereconductedundertwoturbulenceschemes (standard *k*- ω and *k*-ε). *k*- ω for most of the cases agreed withwind tunnel values, even though its less stable. From the flow featuresobtained it was seen that at the front, with very little flow separation theunique shape near the mouth region allowed transition into the back. Atthe rear due to the diffusion process from all sides CD is reduced from thepressure recovery of the fuel. The simplified model of the boxfish wasfoundtohaveadragcoefficientof0.073ataReynoldsnumbersequivalentto 100 km/h of inflow velocity. The boxfish design was found to be moreefficientatminimizingtheaerodynamicdrag[35].By utilizing the FLUENT programming and other numerical reproductiontechniques to think about the impact of a car's tail on its streamlinedexecution,andbreakingdownalternatefactorsthatimpactacar'soutsidestream field, this strategy can viably give a reference of what models ofcars are perfect for model making for future wind tunnel tests. Upgradingvehicle tail configuration can enhance the dynamic execution of car, theenhancedcarmodel'sdragcoefficientwasfoundtobearound4.5%lowerthan the essential model, and the lift coefficient was around 41.6% lowerthanthefundamentalmodel,enhancingthemodel'sstreamlinedexecutionaltogether.Theaerodynamicperformanceofavehicleisgreatlyinfluencedbythemirrorsandwheels.Withgroundclearancediminishing,the drag coefficient diminishes constantly; the lift coefficient expands first,andatthatpointdiminishes,foralittlevehicle.Thebiggergroundclearanceimprovesvehicle probability[36].Aprototypecarcalled“HorasMesinUSU”plannedbyUniversityof SumateraUtaratotake partinthecontestofenergyefficiencywastested.In the outcomes, path-line, speed vector and weight appropriation areplotted. By utilizing the pressure appropriations, drag and lift coefficientsarecomputed.Withtheendgoaltomakeanexamination,thestreamlinedqualities of the present concept are contrasted with a production car“Ford-Fiesta”. The Horas Mesin USU had a drag coefficient of 0.29598 onan average and Ford-Fiesta had a drag coefficient of 0.24320. Then again,the found lift coefficients of the Horas Mesin USU and Ford-Fiesta are0.09485621and0.03192202respectivelyonanaverage.ThisrealityproposesthatFord-Fiestahasasuperiorstreamlinedexecutionincorrelationwith HorasMesinUSU.Itisrecommendedtoperforminvestigation to enhance the streamlined execution of Horas Mesin USU[37].Theproposedtechniquesforthestreamliningofdragofthecarbyexpandingthefrontwindshieldpointandshapeimprovementdemonstrates that the second case give less drag additionally a superiorstreamlined trademark, and was affirmed by the 2D and 3D investigationof“BMW3series”vehiclewhichhasbeeneffectivelydoneonbothexistingandoverhauleddemonstrate.Theoutcomedemonstratesincredibleconcurrence with the wind-tunnel test result for the first model, while theoverhauled 3D show has better optimal design when contrasted with thecurrentmodel;thedragcoefficientwasdiminishedby8.85%.Thetallnessof the vehicle was lessened by 6.7 cm in the overhauled vehicle. From theCFD results, it is clear that just expanding the point between the frontwindshield andmotorhood withoutmodifyingtheouterstateofthevehicledoesnothaveamajorimpactontheestimationofthestreamlineddrag. While expanding the front windshield point and modifying the stateofthecarimpactsthestreamlineddragandmorestreamlinedwindcurrent[38].Table.3comparesnewdesigns.

TABLE3. Comparingnewdesignconcepts

Vehicletype	Description	Advantages	Limitations	Remarks
boxfishdesign[35]	Bio-mimicryofyellowboxfishofOstraciidaefish family.	CD= 0.073at a Reynoldsnumbersequivalentto100km/hofinflowvelocity.	Shapeofthevehicleisdifferentfromconventionalvehicles	The CDvalues are lesserthan the values of normalvehicles
Newtailshapeof car[36]	Upgradingthetail-shapeofthecartoimproveair flow	Dragwasreducedby4.5%andlift wasdecreased	Onlythetailshapehasbeenstudied	Otherpartsalsohavetobeconsidered
HorasMesinUSU[37]	Thenewdesignwascomparedwithrespecttofordfiesta	The CD and CL were found to belesserthanfordfiesta	The fordfiestahad betteraerodynamiccharacteristics	Thedesignfailedto bebetter than anyproductioncar.

Car with expandedwindshield[38]	Expandingwindshieldtostudytheaerodynamiceffects	The dragcoefficientwasdiminishedby 8.85%.	expandingthefrontwindshieldofthecarimpactsthestreamlineddragandwindcurrent	Thechangeonthevehicledidnot have any majorimpact.

CONCLUSIONS

Thisreviewonrecenttrendinaerodynamicperformancedevelopments in automobiles is built based on three key areas forheavygoodsvehiclesandlightvehicleswhich arecars:Reduction of drag: The non-streamline shape of the heavy vehiclescausesalotofaerodynamicdragtoactonthem,whichcauseseveralill effects including reduced performance, increased emissions, andincreased fuel consumption. From the papers it can be seen that theattempts to reduce drag on heavy vehicles have been done usingseveral types of external add-on parts like skirts, front fairing, flaps,andvortexgeneratorsandsoon.In[1]26%reductionindragcanbeachieved by using external attachments which involved covering upof most of the gaps such as gap between tractor and trailer unit andalso by using side skirts to cover up the space between the wheelsandbyusingafrontfairingtostreamlinetheflowasmuchaspossible. However this experiment was done on a scaled model sotheactualsizemodelmayhaveslightlydifferentvaluesforreductionof drag. The ground clearance will also be reduced. From differenttypes of vortex generators used the vane type of VG did performbetter when the size was bigger and placed to the front end of thetrailer.Incarsitwasseenthattheattackangleofthespoilerplaysanimportant role in either decreasing or increasing the coefficient ofdrag. The angle of attack is dependent on the shape of the aerofoil.The combination of different add-ons like front wing, diffusers, andrear wing all help in reduction of drag, and each part can eitherincreaseor decreasethedrag.Instability caused due to the aerodynamic effects: The main reasonfor instability of heavy vehicles are crosswinds acting on the side ofthe vehicles which may cause the vehicle to roll over,and thesecrosswindeffectswillalsobedependentonthesurroundingelements.Therolloverisveryhighforthevehicleswithla rgersurface areas on the side, and is lesser for the vehicles with rounderandsmothersurfaceonthewindwardside.Incarstheliftisthemainreason for instability and difficulty in handling. The stability can beobtained by creating enough down-force. The down forces can becreatedbyusingreardiffusers,rearspoilers,andfrontspoilerandsoon. The techniques used by race cars can also be implemented on tothe passenger cars up to a certain extent, but the cost of productionmayturnouttobeimpractical.Designoptimization:Manyexperimentshaveshowndatatoobtaintheareaswhi chrequiredevelopmentsintermsofdesigns.Thestagnation zones, high pressure areas, wake area, flow turbulenceand streamline flow, and many other reaction to the air was foundout. The box fish type of design inspired from box fish is a designcapable of producing a lot of reduction in drag compared to thenormal design of the vehicle. But using this kind of design might notbe aesthetically appealing compared to the design trends for cars asofnow.Improvementofthedesign canbedonemyoptimizingonlyacertainportionofthevehicle.Propermeasurementsmustbemadebefore rendering a new design as it can perform lesser than thealreadyexistingdesigns.

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