Design and Development of Multi Element Wing for Automobile Application

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Abstract
Vehicle aerodynamics is a broad encompassing field that describes the forces acting on an object when moving through a fluid. When stationary, the exterior surfaces of an automobile experience one atmospheric pressure; the upper and lower surface as well as the front and rear surfaces all have the same pressures exerted and ultimately achieve equilibrium with the summation of forces being equal to zero. As the vehicle starts to move through the fluid, the pressures exerted on the exterior surfaces change proportional to the square of velocity. These pressure changes create forces acting on the surface of the vehicle that can drastically hinder the performance of the vehicle. Aerodynamicists study this natural phenomenon to try and minimize forces that inhibit motion and, in some cases, develop these forces and use them to improve performance and safety. Vehicle aerodynamicists are primarily concerned with two dominant forces that interact with a vehicle; lift and drag. The management of these forces is crucial to the performance of any vehicle however the philosophy of vehicle aerodynamics differ significantly depending on the application. In this work introducing multi element in the rear of the vehicle to maintain the lift force and computational fluid dynamics analysis carry out to measure the performance of the multielement wing.

Keywords: vehicle aerodynamics, computational fluid dynamics analysis, Multi element wing

1. Introduction
Aerodynamics is a very large domain in automotive engineering. It is almost impossible to design a car now days without considering about its aerodynamic efficiency. Motorsport is almost unimaginable without the wizardry of aerodynamic parts. There are various ways in which reduction of drag can be achieved such as reduction of frontal cross-sectional area of the car, reducing parasitic drag, etc. But aerodynamics in cars is more efficient and has a crucial role when it provides more traction for the interaction between wheels and ground surface. This traction force on the wheels is mainly generated due to aerodynamic down force. Down force helps to increase traction at the wheels which can help to increase cornering speed of the car.[1] It also helps to improve the overall stability. For instance, the automotive and transportation industries seek to minimize the drag force to improve fuel economy at highway speeds. The aviation industry seeks to maximize the overall efficiency or lift divided by drag of their vehicles.

The more lift produced, the larger loads the aircraft can carry and the smaller drag force allows for better fuel consumption. One such device used for generating down force in car is
wing. Wings were initially meant for lift force which helps an aeroplane to fly. But inverted configuration of the same wing can be used to generate downforce in cars. It is said that in formula 1 cars after certain particular speed the car can be driven upside down due to the downforce it generates. [2] Wings are basically made up of aerofoil structures. Wings are majorly used at 2 locations in a car which is the front end and the rear end. The front wing of the car is comparatively smaller in size than the rear wing of the car. Moreover, the wings work under the principle of ground effect, that states more and more downforce can be generated depending upon the distance between the aero device and the ground. [3] The lesser the distance, more is the downforce. Wings basically comprise of inverted aerofoil structures.

Wings are classified into single element wings and multi element wings. Basically, multi element wings are a technique used to generate more and more down force. A single element wing cannot generate the amount of force that a multi element wing generates. A multi element wing further can be classified according to the number of elements it comprises as shown in figure 1.

Multi elements wings are major devices to create significant amount of down force and are easiest way to do so. They find their application majorly in formula cars such as formula 1 and formula student. The basic principles and methodologies on how a wing works can be studied in some of the famous books such as Race Car Aerodynamics by Joseph Katz and Competition car Aerodynamics by Simon Mcbeath. A great insight towards designing of a wing can be found in numerous research journals majorly in formula student papers.[4] Also, the analysis techniques and practical experimental approach is of greater importance when it comes to validation of the designing procedure. A multi element wing is a structure made out of certain number of air foil structures in a specific orientation. Usually there is an option between whether to use single element wing or multi element wing. Single element wing is made out of single air foil structure to obtain desired amount of forces. The magnitude of force generated is basically decided by the geometry of the air foil.[5] It also depends upon the application where the wing is required.

Air foil structures can be of any kind of geometry. Air foils find their application in lots of aerodynamic devices such as propellers, fins, windmill blades, aeroplane wings, etc. So, to choose a specific kind of air foil for desired application is a crucial task. This task can be further complicated by generating own air foil geometry. Deciding own camber line geometry, chord length, leading edge radius, trailing edge radius, etc. But if the generation of this sort of air foil is successful, then it is the best result because it is only dedicated for the application desired.
Since air foil geometry is not the main issue for this project, hence it was deciding to use basic air foil geometry from online database. The major idea of this project is to study about the design of multi element wing. Obviously a multi element wing has a greater drag force compared to the single element wing but when it comes to down force generation of wing the multi element is always better than single element wing.[6] The motorsport industry has witnessed several different types of wings since it was started. Cantilever wings, slender wings, tower wings, t wings, dihedral wings, etc. Usually multi element wings can be consisting of two, three, four or five elements. Higher the number of elements, greater is the magnitude of forces generated from it. The major doubt while designing a multi element wing is the orientation part of it. A proper orientation and alignment of the air foil structures is very important to know the efficiency of the multi element wing compared to single element wing.

As a primitive level of designer, there is always a doubt related to the angle of attack and orientation of air foil geometry. Since angle of attack of 2D air foil is determined using 2D analysis of it. It is ideal to use that very same angle of attack for designing of a single element wing for correct amount of drag force and down force according to its cl/cd plots. But when it comes to setting angle of attack for multi element wings the ideology may be same to that of single element wing or maybe not.[7] The angle of attack for each and every element needs to be carefully decided so that there is a constant attachment of air flow throughout. the air foil geometry. The attached flow of air is crucial because, longer the air is attached to the wing surface better is the result of forces.

The vast information regarding types of wings and working of wings can be studied through the books related to aerodynamics of ground vehicles. Whereas the designing part of the wings can be understood by referring various research papers and design reports of various international formula teams.[8]

2. Methodology

2.1 Design of air foil structure:

The methodology for this project starts on a basis of strong knowledge background. Lots and lots of reports from various journals and books were referred to gain appropriate amount of knowledge about Aerodynamic Wings which find application in Automotive area. After the research for the specified topic has been completed the basic idea was to design certain number of iterations of a multi element wing and select the best one out of them by comparing the CFD results of each and every iteration. For 3D CAD modelling PTC Creo software version 5 is used. But before all the designing parts starts, major task is to select appropriate air foil geometry which suits the desired application field.[9] So, couple of air foil database were searched thoroughly and with reference of some research paper we were able to shortlist some basic air foils for primitive design and ideation. These shortlisted air foils were then categorised accordingly to their Reynolds number and were then 2D analysed using software Xflr5 Xfoil. For 2D analysis the air foil geometry is imported into the specified software and plotted accordingly as shown in Figure2. After the air foil has been plotted, certain boundary condition settings are done such as Reynolds number range of the working speed and number of step and intervals etc.
After the angle of attack of airfoil has been decided the geometry and dimensions of airfoil is decided. An arbitrary value of chord length of main element of the wing was decided as 250mm. The same airfoil was decided to be used for the second element also known as flap. But before a multi element wing was designed a single element was also designed and analysed. To know the difference between multi element and single element wing this was essential step to be followed. As concluded by lots of research paper and books the multi element is definitely better than single element wing because the efficient camber length that we get from multi element wing is greater and more efficient. The attached air flow in multi element wing was better achievable.\[10\] For both single element and multi element wing the same procedure of designing and analysis was followed.

![Figure 2: 2D structure of airfoil](image)

![Figure 3: 3D model of single element wing](image)
The constructed wing is then saved in basic PTC format first and then in .stp extension. So that it can be easily imported in the CFD software.

![3D model of multi element wing](image)

**Figure 4:** 3D model of multi element wing

### 2.2 CFD:

The CFD software is then started and the saved step file is imported using the import option. Using parts option under geometry a topology block was created using specific dimensions. The inlet outlet surrounding and ground faces of the topology block were splatted using split by patch option. Split by patch is offered to all the topology surfaces and it is done by selecting the split by patch option in the right click drop down menu of the surface tab of topology box. After all the surfaces are allotted for the topology box, the topology geometry and the imported wing geometry is made into a region by selecting all the geometry parts and using the option “assign parts to region”. After all the parts are defined into a region, new mesh continua can be generated. The meshing models selected for this process are:

- Trimmer.
- Prism layer remesher.
- Surface remesher.

Next step is to put values according to the topology size. Values for cell size, etc The base size ratio is set to be as 0.05, prism layer thickness percentage relative to base in term of percentage is set to be 15 percent, overall surface mesh size is set to be 50 percent for relative minimum size and for relative target size it is set to be 150 percent because throughout the topology refined mesh is not required. For refinement around the wing geometry, wing under region tab is expanded and the mesh values for it are changed. Custom prism mesh and surface mesh options are selected. Number of prism layers for the wing is selected to be 5 and surface size is reduced to 5 percent of base and target size is reduced to as low as 10 percent with the value being 5mm. The prism layer thickness for wing is selected to be 7 percent. As refined mesh is not required for the inlet and outlet surfaces of topology. The prism layer mesh is turned off for the inlet and outlet surfaces. After all these settings are done initially the surface mesh is created which takes the least amount of time. After surface mesh creation has been completed,
the surface mesh is reviewed and after it is considered to be refined enough, the volume mesh for the system is generated. The volume mesh size differs from 1 million cells to 3 million cells for different iterations. All the surface capture for the geometry is analysed and deformations are corrected by changing values. After mesh is created, a physics continuum is created for all the physics condition setup and boundary conditions.

2.3 Physics models used in CFD

- All $y+$ wall treatment
- Gas
- Gradient
- Ideal gas
- K omega turbulence
- Reynolds-averaged navier stokes equation
- Segregated flow
- Segregated fluid enthalpy
- SST-menter k omega
- Steady
- Three dimensional
- Transition boundary distance
- Turbulence suppression
- Turbulent

After all the physics conditions a scalar scene is setup to view the pressure distribution over the entire wing surface. Under displayer tab, in parts section the entire wing surface is selected and scalar field is selected as pressure. Force reports are generated under the report’s sections with appropriate directions. Monitor and plot for these force reports are generated.

A scaled version of wing which fits into the testing section of the wind tunnel can be 3D printed and mounted appropriately. As the maximum speed at which the wing can be tested is 20m/s, our prototype can be analysed at certain set of speeds such as 45kmph (12.5 m/s) and 20m/s.

45kmph is the base working speed of the wing which will be tested and to the max potential it will be tested at max possible speed which is 20m/s. The air flow can be visualized using different flow visualization techniques. A rigorous procedure of tracking the experimental values should be followed in order to know the pressure difference. Through the pressure difference of the upper surface and lower surface of the wing the desired forces can be obtained.

3. Results

Getting an attached flow throughout the entire main element was a difficult job. The aerofoil selig s1223 was initially iterated according to its angle of attack following with its flap element. But the attached flow was difficult to obtain as the curvature was getting to steep for the boundary layer to stay attached. Hence after 1/4th chord length distance the flow was getting separated. Several iterations were made to make the flow attached by iterating the flap angle
and the main element angle but there was no sign of attachment in CFD. After a thorough study about the air foil we were able to conclude that the selig s1223 air foil was supposed to functional when only used as a single element wing along with its desired angle of attack.

![Figure 5](image_url)

**Figure 5:** Pressure plot of basis iteration of wing

![Figure 6](image_url)

**Figure 6:** Pressure distribution over wing surface isometric view

The velocity vector and tracking the particle while subjected to a boundary condition will give the appropriate values and the second element will continue the attached flow in such a way that reduce the drag force. pressure plot of multi element wing as shown in figure 6.
4. Conclusion
A two element multi element wing was successfully designed and analysed. Compared to the initial iterations an efficient arrangement and orientation of air foils was achieved. A considerable reduction in drag and enhanced down force magnitude was achieved with the final iteration of the wing. An attached air flow region can also be viewed at the underside of wing. hence whenever a multi element wing is being designed, a proper arrangement of air foil should be ensured in order to get efficient airflow underneath and satisfactory force values.

References
[1] Van Dam CP 2002 The aerodynamic design of multi-element high-lift systems for transport airplanes. Progress in Aerospace Sciences 38(2) 101-144.
[2] Arnal D and Juillen JC 1990 Leading-edge contamination and laminarization on a swept wing at incidence. In Numerical and physical aspects of aerodynamic flows 4 391-402.
[3] Hardy B 1989. Experimental investigation of attachment-line transition in low-speed, high-lift wind-tunnel testing. Fluid Dynamics of Three-Dimensional Turbulent Shear Flows and Transition 3 2-1.
[4] Lockyer AJ, Alt KH, Kudva JN, Kinslow RW and Goetz AC 1997 Conformal load-bearing antenna structures (CLAS): initiative for multiple military and commercial applications. In Smart Structures and Materials 3046 182-196.
[5] Ross JC, Storms BL and Carrannanto PG 1995. Lift-enhancing tabs on multielement airfoils. Journal of Aircraft 32(3) 649-655.
[6] Platzer MF, Jones KD, Young J and Lai JC 2008. Flapping wing aerodynamics: progress and challenges. AIAA journal 46(9) 2136-2149.
[7] Palanivendhan, M., Wadhawan, M. and Selvagandhi, R 2015. Upper-limb shape memory alloy orthosis for restoration or improvement of basic hand functions Indian J. Sci. and Tech 8 795-799.
[8] Englar RJ, Smith MJ, Kelley SM, Rover III RC 1994 Application of circulation control to advanced subsonic transport aircraft. Part II-transport application Journal of Aircraft 31(5) 1169-1177.
[9] Hirsch J 2011 Aluminium in innovative light-weight car design. Materials Transactions 52(5) 818-824.
[10] Mills JK and Ing JG 1996 Dynamic modeling and control of a multi-robot system for assembly of flexible payloads with applications to automotive body assembly. Journal of robotic systems 13(12) 817-836.