International Journal of Advance Research and Innovation
Vol. 8(3), Jul-Sept 2020, pp. 72-83
Doi: 10.51976/ijari.832012

Article Info

Received: 11 Jan 2020 | Revised Submission: 29 May 2020 | Accepted: 30 Jul 2020 | Available Online: 15 Sept 2020

Comparative Study of Different Missile Shapes using Computational Fluid Dynamics

Gaurav Kumar, Rohit Kumar**, Sagar Dagar*** and Raj Kumar Singh*****

ABSTRACT

Aerodynamics study using computational fluid dynamics is very famous among the engineers and scientists, because it not only reduces the cost of the entire project but also saves a lot more time. The results of the CFD simulations needed to validate through experiments. So, we can say that CFD simulation studies reduce the no. Of experiments taken, if it cannot eliminate. In this research paper, we made four different aerodynamics missiles shapes CAD models in solid works by using underlying principles, mathematical equations of different curves and engineering judgement, one of them is a missile of standard basic shape. We have analysed and compared them with basic shape of missile. Here, in this study, Volume is taken a constant parameter. Drag Coefficient is the main parameter which is evaluated and studied at different Mach no's and at a constant angle of attack. Reasons behind the magnificent drop in drag coefficient explained in discussion section.

Keywords: *Missiles; Fluid dynamics; Flow separation; Drag force; Drag coefficient; Comparative study; Aerodynamics CFD.*

1.0 Introduction

For development or modification of expensive machine or system there is a need arise to make a model before making it in real size so that we can clarify most of the problems in less perimeter which results low cost, but for making some specific parts like jet engine missiles etc. It is not suitable at all. So there is a need of computer science by which we can easily get the final result approximately equal to the actual result and also very complexity is being solved by using the computer and this process of imitation is called the simulation process

CFD simulation is one of the complex simulations by which many fluid dynamics processes and systems are being simulated over the decades CFD simulation uses many complex relations and numerical algorithms. As the human needs increases there is a continuous improvement in the CFD simulation, and very expensive systems such as wind tunnel and various types of experimental testing systems are present in this software. CFD simulation is being proved a very useful and inexpensive tool over the last few decades, but for analysis of the high complexity there is a requirement of great performance of the processor, graphic tools etc. Mostly it is used for the engineers for finding the flaws in the model and all the possibilities of technical failure and for study and analysis of the dynamics of the fluid over it. Advancing in the turbo machines and reduced noise are some common difference and considerable changes can be made by the CFD simulation. In India most of the missile designers are heavily dependent on the CFD simulation for getting results very close to the actual in propulsive and aerodynamic parameters.

Missiles are the propulsive explosive which can destroy a large area and its construction in real life is too dangerous so it is being necessity to design and analyse missiles on the CFD tool. CFD tool contains the Euler, navier stokes and other compressible fluid flow equation for the analysis of high speed aircrafts

**Corresponding author; Department of Mechanical Engineering, Delhi Technological University, Delhi, India (E-mail: gauravdtu@hotmail.com)*
***Department of Mechanical Engineering, Delhi Technological University, Delhi, India (E-mail: rk868616@gmail.com)*
****Department of Mechanical Engineering, Delhi Technological University, Delhi, India (E-mail: sagardtu@yahoo.com)*
*****Department of Mechanical Engineering, Delhi Technological University, Delhi, India (E-mail: rajkumarsingh@dce.ac.in)*

and missiles. In the CFD simulation tool we are able to explode it at any position such as in air or land on a specific co-ordinate, also we can measures the total drag experienced by the missile during the total flight. Also we can easily determine the speed and time and exact position if the wind speed varies from different positions. There may be some other flaws like development of oblique shock waves and heat transfer during flight air friction by which energy is being lost. So, at what rate of propulsion is required for getting a specific speed with highest precision. High precision is being very necessary for blasting an aircraft so, CFD simulation can also be helpful for determining the possibility of the successive collision of missiles.

2.0 Computational Fluid Dynamics (CFD) Modelling

The development of computer plays an important role in the modern science and technology. The computer brings about computational fluid dynamics (CFD), computational structure mechanics, computational electromagnetism, etc., which produce great impact on modern aeronautics and astronautics. CFD has now been an essential tool for the aerodynamic design of aeronautic and astronautic vehicles, Next, CFD simulations were carried out to validate the results obtained from the VLM approach and to analyze the flow around the wing at high angles of attack.[1]

Whether the missile can be launched safely or not from a helicopter is a very important problem which should be taken into consideration in the design of a helicopter. The complete set[3] of three-dimensional (3-D) time-dependent Navier–Stokes equations is solved in a time-accurate manner for simulations of unsteady flow fields associated with projectiles during flight. domain of aerospace and aviation, the existence of flow separation leads to the generation of noise, the reduction of lift and the instability of flying vehicles. Researchers have been searching for the flow separation control method for a long time.[4] Generally, quasi-steady flow computation methods are adopted to calculate various release trajectories of external stores under aircraft with fixed wings. However, unsteady flow computation methods should be used to simulate the flow around a helicopter because of its rotating rotor. When it occurs, the increment of lift coefficient with angle of attack began to decrease until the maximum lift coefficient value is reached. Afterwards, when angle of attack is still increased, the lift decrease appears [5].

This paper challenges the CFD community to take on the full flight simulation problem. This challenge is referred to as Digital Flight and is defined as the ability to simulate in a computer a flight manoeuvre satisfying the governing flow equations, the aircraft Aeroelasticity characteristics, the 6-DOF equations, the flight control system, and the propulsion system. In short, we want to fly an aircraft in the computer. The missile model reliability was proved comparing numerical and experimental results in regards to pressure coefficients and aerodynamic forces (i.e. drag, lift and moment coefficients)[2]. Separation on smooth curved surfaces is more challenging as the point or line of separation is not fixed in space and is very sensitive to external flow properties. [6]

Since separation is associated with significant performance losses, its mitigation becomes important [7]. A Blasius boundary layer is known to transition to turbulence through several mechanisms, known as the K (Klebanoff) [8] Transitional flow is a complicated phenomenon. The exact point of laminar-turbulent flow transition is challenging to define and is often based on empirical data with large uncertainties obtained in the experiments mostly using air or water [9].

However, there are some situations that the transition regime cannot be avoided, such as upgrading the system as it working originally in the laminar flow or in the accidental scenarios. Until now, limited work in the transition region has been reported due to the complexity of the influence factors [10]. The transition process is initiated through the growth and development of disturbances originating on the body or in the freestream. Environmental disturbances include atmospheric turbulence, entropy spottiness, particulates, and electrostatic discharges [11].

3.0 Missiles Models Used in This Paper for Comparative Study

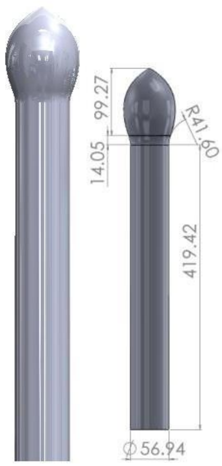
3.1 Case 1

Missile 1, as shown in figure 1, looks like a normal cylindrical shape, which is looking like a half oval as a cap resting on that cylinder, but at the front the oval is keeping sharp for minimize the coefficient of drag.

Figure 1: Missile 1 (Dimensions are in mm)

Figure 2: Missile 2 (Dimensions are in mm)

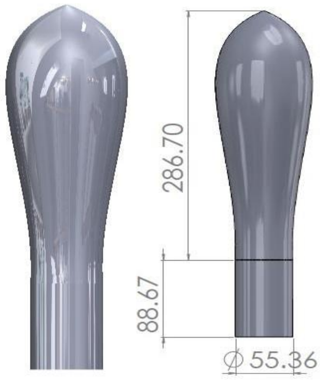
Figure 3: Missile 3 (Dimensions are in mm)



As shown in figure 2, the main body of this missile is also remained cylindrical shape but in the front portion, width of the missile is larger than diameter of the cylindrical part, front part is looks like a Case 2 with a sharp nose.

From figure 3, the main body of this missile is also remaining in cylindrical shape but as we moving at the top its diameter is increases and at the point where the diameter is becomes almost 3/2 of cylinder diameter and then it becomes a half spherical shape with a sharp nose.

Figure 4: Missile 4 (Dimensions are in mm)



4.0 Results and Discussion

4.1 Case 1

4.1.1 At mach no. – 0.2

Figure 5: Pressure Effects

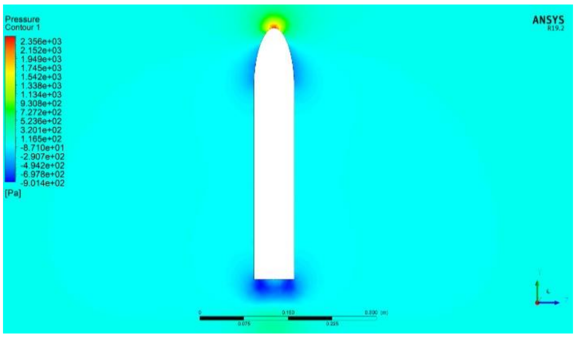
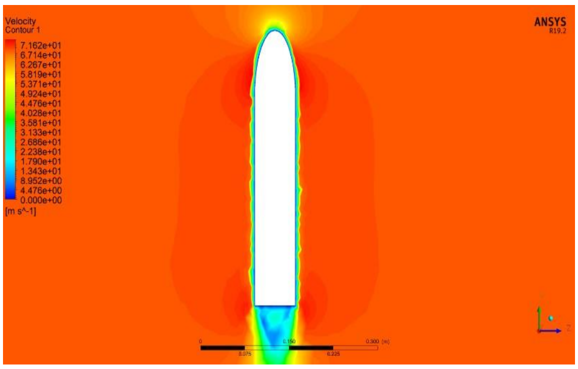


Figure 6: Velocity Effect



4.1.2 At mach no. – 0.5

Figure 7: Pressure Effects

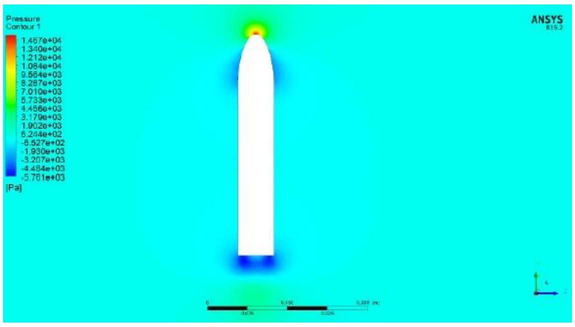
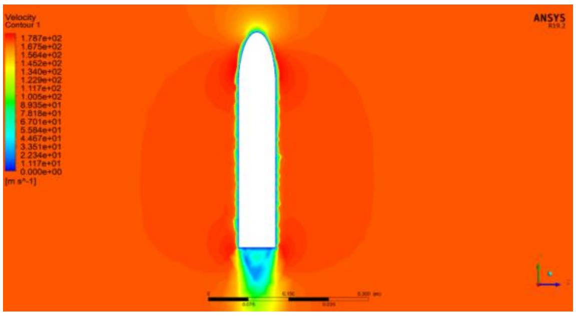


Figure 8: Velocity Effects



4.1.3 At mach no. – 0.75

Figure 9: Pressure Effects

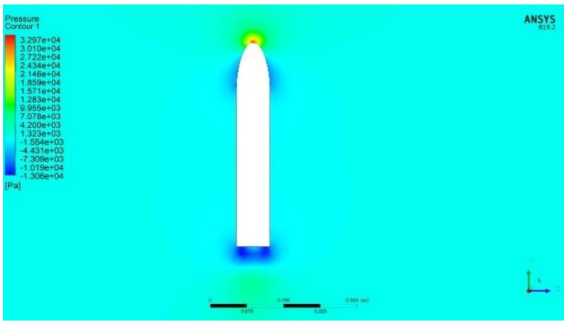
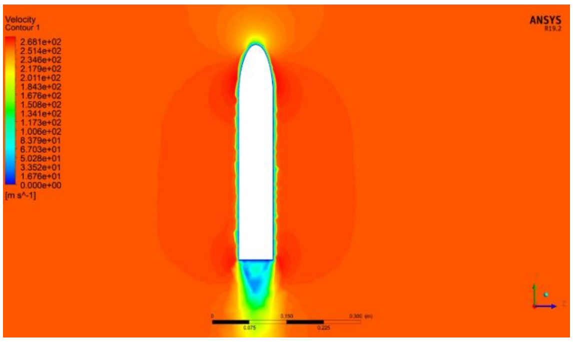


Figure 10: Velocity Effects



4.1.4 At mach no. – 1.0

Figure 11: Pressure Effects

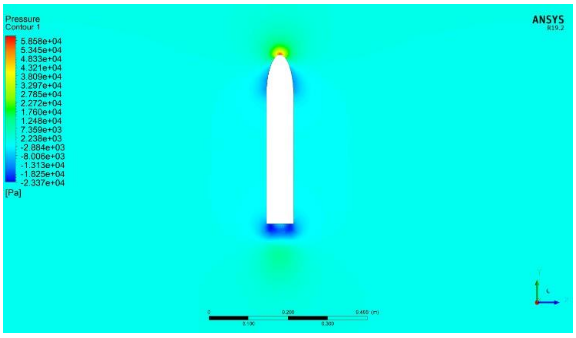
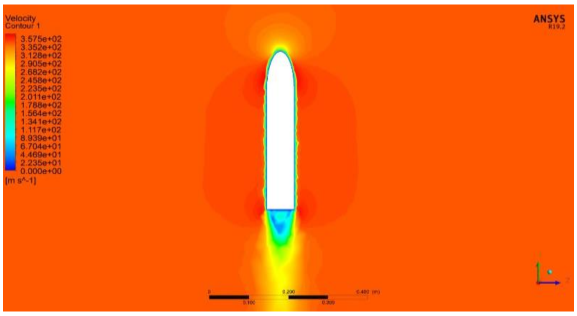


Figure 12: Velocity Effects



4.1.5 At Mach no. – 2.0

Figure 13: Pressure Effects

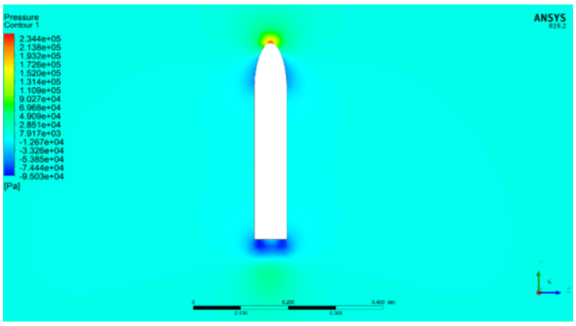


Figure 14: Velocity Effects

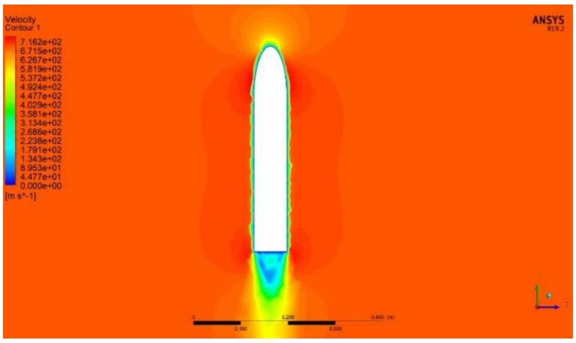


Figure 15: Coefficient of Drag vs Mach Number for Case 1

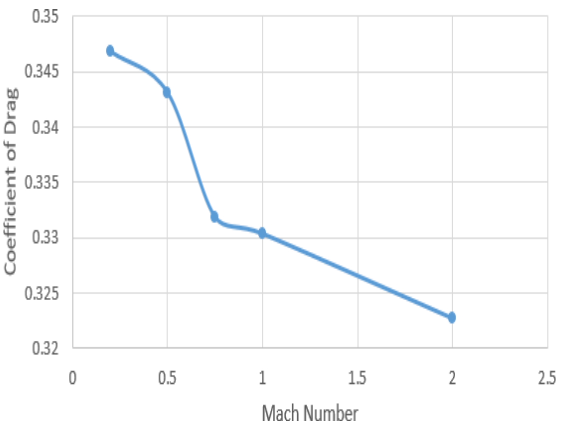
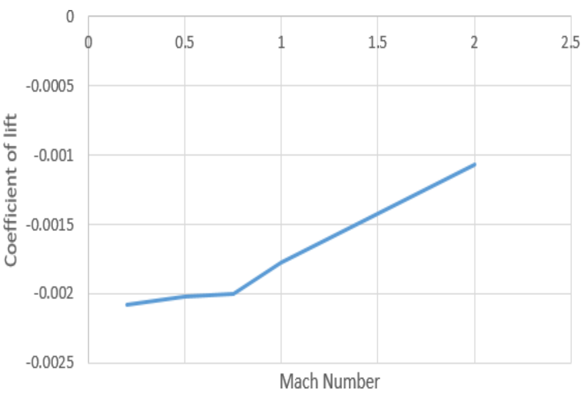


Figure 16: Coefficient of Lift vs Mach Number for Case 1



In Case 1, there is very high pressure at the tip of the missile and there is a vacuum pressure after the tip and a very high vacuum pressure is being created on the tail of the missile ,for boundary layer at the tip of the missile there is a thick boundary layer and then a very thin boundary layer is formed and again at the tail of the missile a very thick velocity boundary layer is formed.

For Case 1, coefficient of drag is decreasing nonlinearly with increase in the Mach number. After reaching 0.5 Mach number it decreases rapidly till 0.75, again after 0.75 Mach number it decreases in small amount. After 1 Mach number it decreases approximately linearly with respect to Mach number.

Coefficient of lift for this missile having very little increment up to 0.75 Mach number, after reaching 0.75 Mach number the curve is approximately linear but very little change is being occurred in coefficient of lift.

4.2 Case 2

4.2.1 At mach no. – 0.2

Figure 17: Pressure Effects

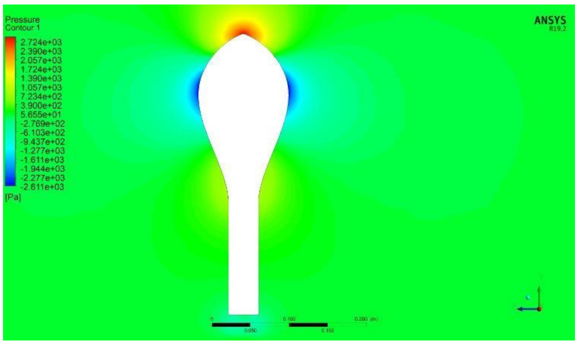
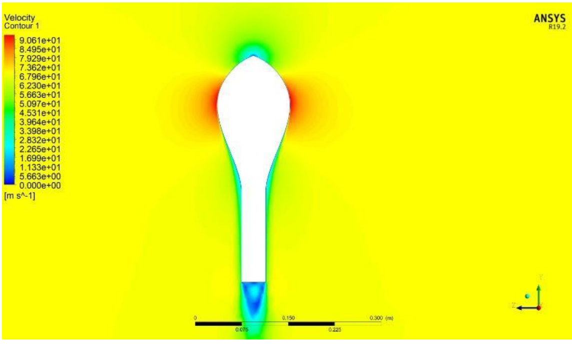


Figure 18: Velocity Effects



4.2.2 At mach no. – 0.5

Figure 19: Pressure Effects

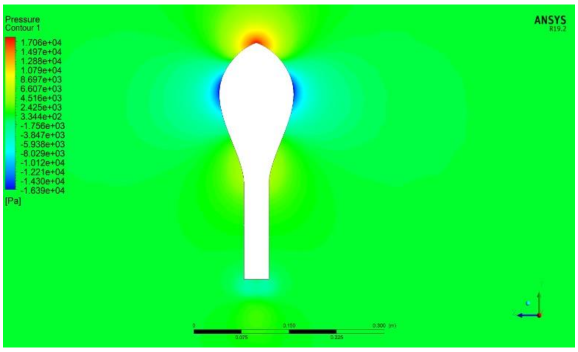
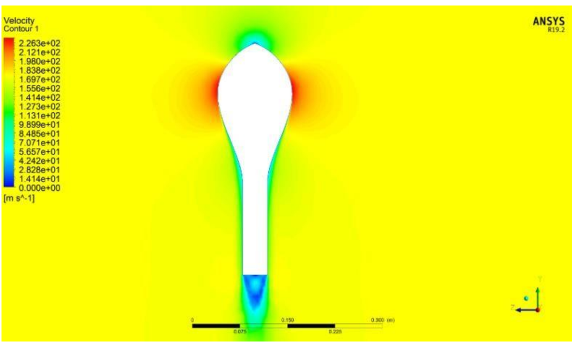


Figure 20: Velocity Effects



4.2.3 At mach no. – 0.75

Figure 21: Pressure Effects

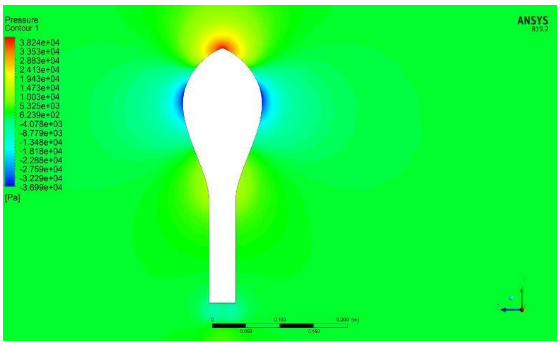
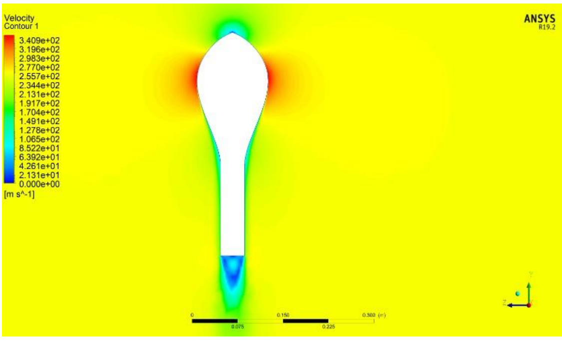


Figure 22: Velocity Effects



4.2.4 At mach no. – 1.0

Figure 23: Pressure Effects

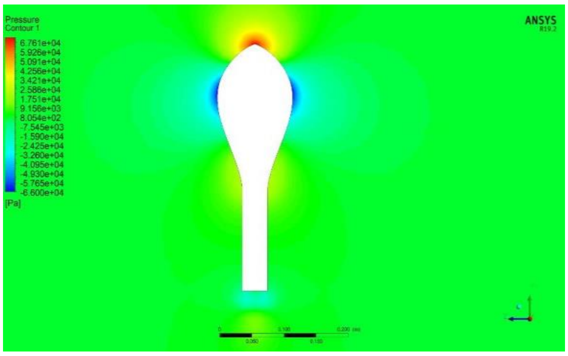
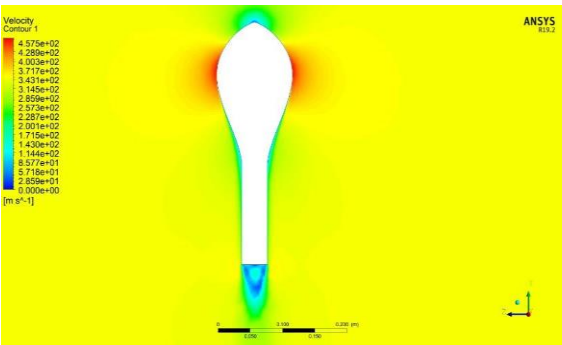


Figure 24: Velocity Effects



4.2.5 At mach no. – 2.0

Figure 25: Pressure Effects

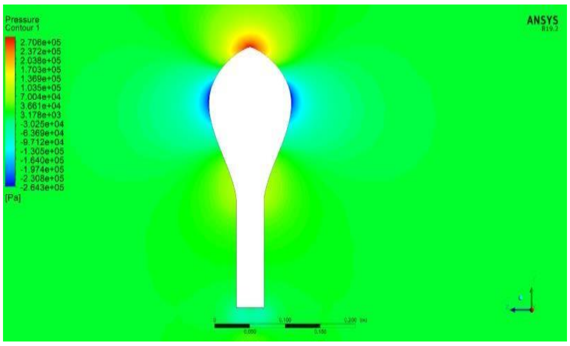


Figure 26: Velocity Effects

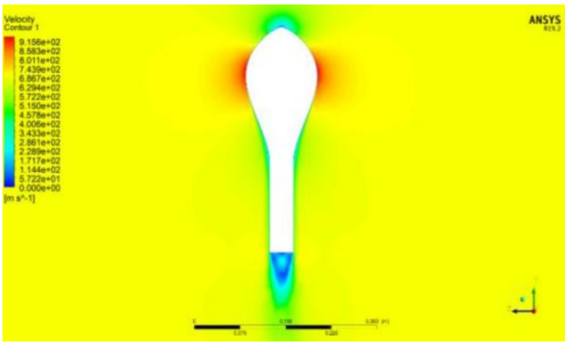


Figure 27: Coefficient of Drag vs Mach Number for Case 2 Missile

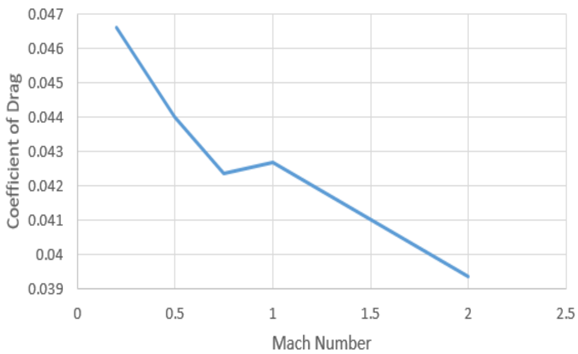
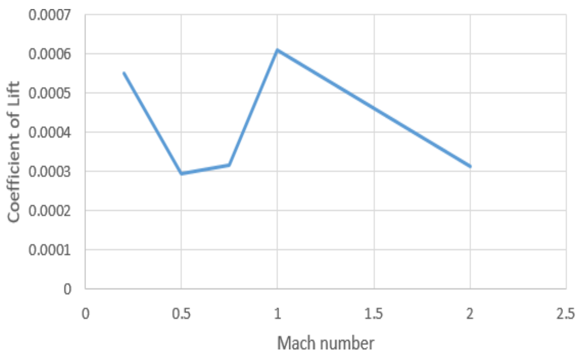


Figure 28: Coefficient of Lift vs Mach Number for Case 2 Missile



Missile in case 2 there is very high pressure at the tip of the missile and then after the tip of the missile there is very high vacuum pressure is developed at very small region, for boundary layer, at the tip of the missile there is sudden decrease velocity and a thick boundary layer is formed and its thickness decreases at the curve of the Case 2 where velocity is even more than free stream velocity and at the tail of the missile the boundary layer separation may be occur and a very thick boundary layer is formed.

The coefficient of drag is free meaning law as compared to Case 1, interest system coefficient of drag is decreases linearly up to 0.75 Mach number, and then it increases negligible till 1 Mach number, and again linear decrement is followed till 2 Mach number.

Coefficient of lift for this missile is varying w.r.t Mach number in irrespective nature, as from 0.2 to 0.5 it decreases, and from 0.5 to 0.75 it remains constant after 0.75 Mach number it increases and after one Mach number it decreases linearly.

4.3 Case 3

4.3.1 At mach no. – 0.2

Figure 29: Pressure Effects

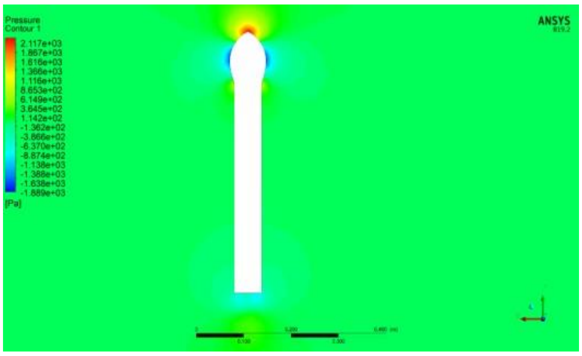
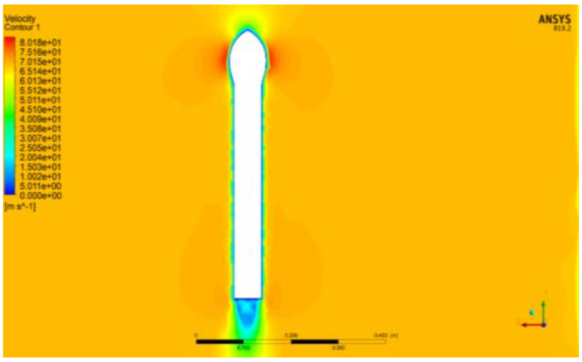


Figure 30: Velocity Effects



4.3.2 At mach no. – 0.5

Figure 31: Pressure Effects

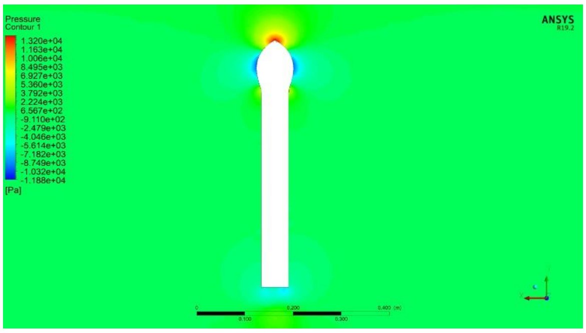
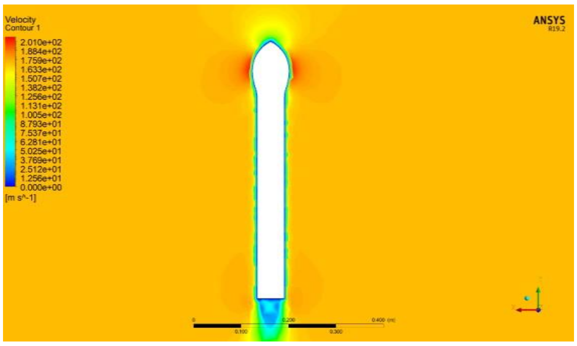


Figure 32: Velocity Effects



4.3.3 At mach no. – 0.75

Figure 33: Pressure Effects

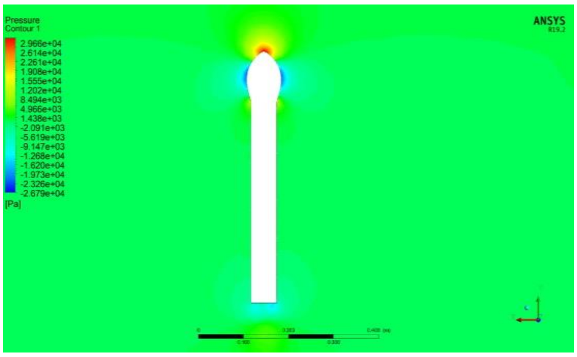
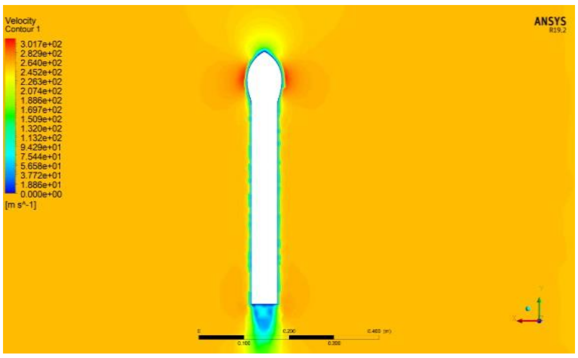


Figure 34: Velocity Effects



4.3.4 At mach no. – 1.0

Figure 35: Pressure Effects

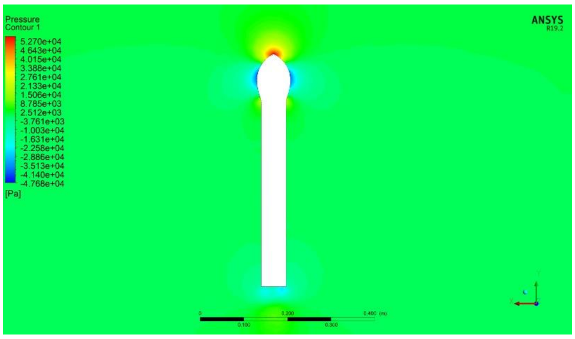
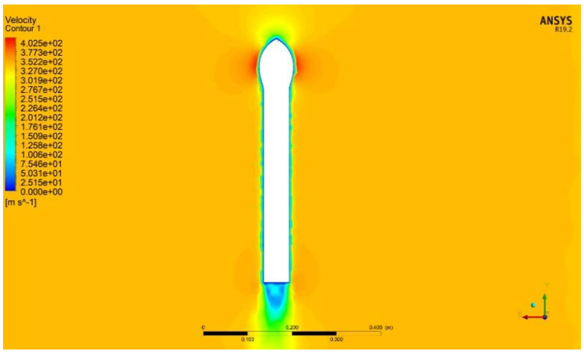


Figure 36: Velocity Effects



4.3.5 At mach no. – 2.0

Figure 37: Pressure Effects

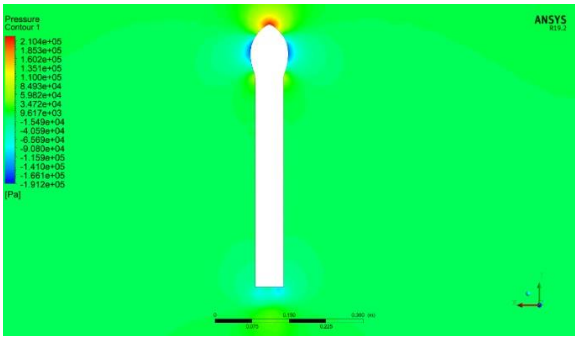


Figure 38: Velocity Effects

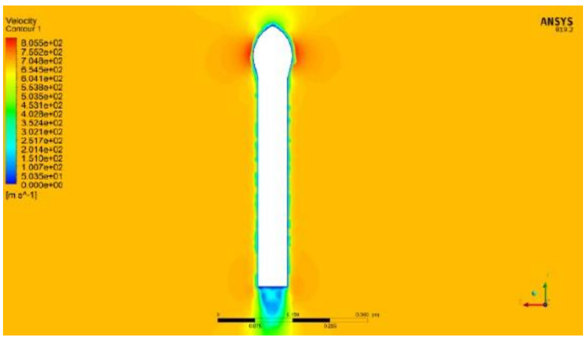


Figure 39: Coefficient of Drag vs Mach Number for Case 3

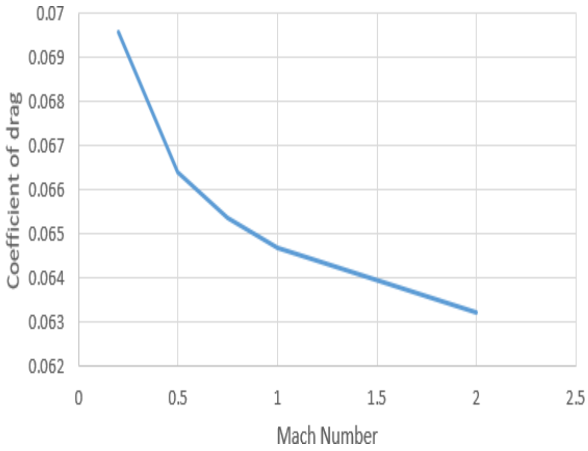
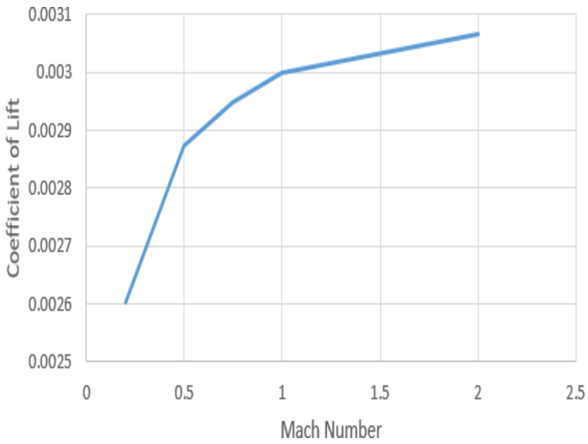


Figure 40: Coefficient of Lift vs Mach Number for Case 3



Here, there is very high pressure at the tip of the missile and at few distance from the tip where vacuum pressure is being found in very small area and at the tail low vacuum pressure is created, for boundary layer , at the tip of the missile there is sudden decrease in the velocity and after a few distance high velocity profile is being created even more than free stream velocity and at the tail of the missile a thick boundary layer is formed also boundary layer separation may be occur.

For Case 3 missile system coefficient of drag is low as compared to Case 1, coefficient of drag is decreases inversely with respect to Mach number, as from 0.2 to 0.5 Mach number it decreases rapidly and then its rate of decrement of Cd is also decreases continuously.

4.4 Case 4

4.4.1 At mach no. – 0.2

Figure 41: Pressure Effects

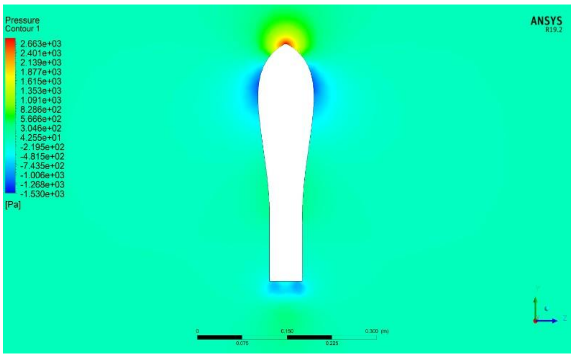
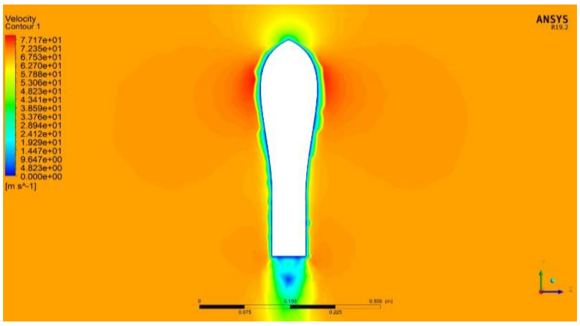


Figure 42: Velocity Effects



4.4.2 At mach no. – 0.5

Figure 43: Pressure Effects

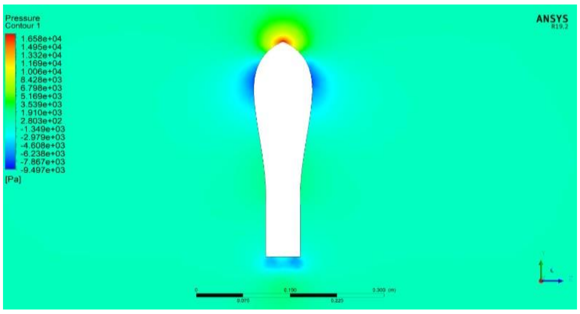
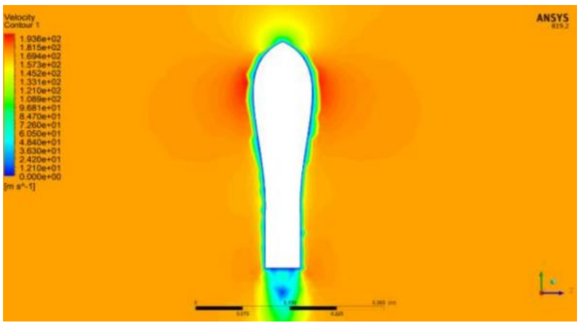


Figure 44: Velocity Effects



4.4.3 At mach no. – 0.75

Figure 45: Pressure Effects

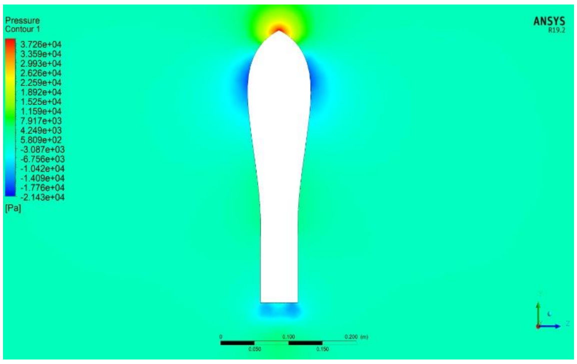
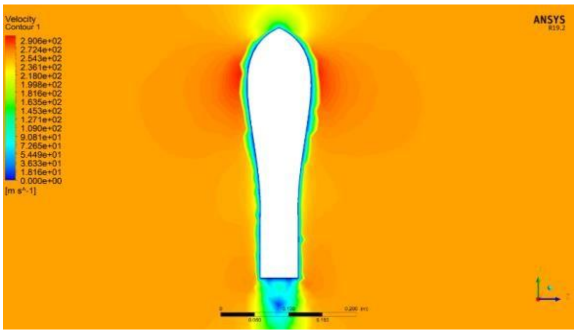


Figure 46: Velocity Effects



4.4.4 At Mach no. – 1.0

Figure 47: Pressure Effects

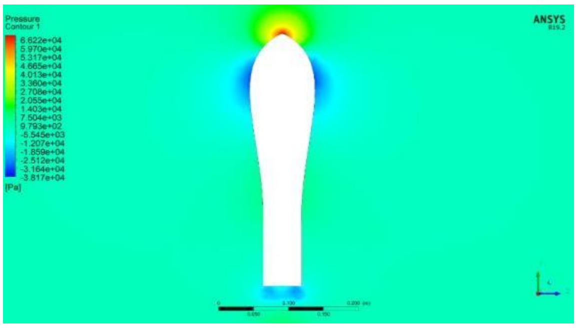
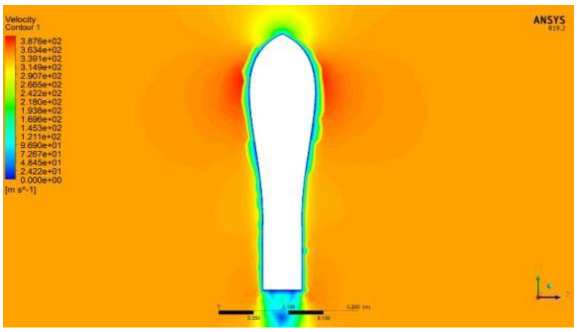


Figure 48: Velocity Effects



4.4.5 At mach no. – 2.0

Figure 49: Pressure Effects

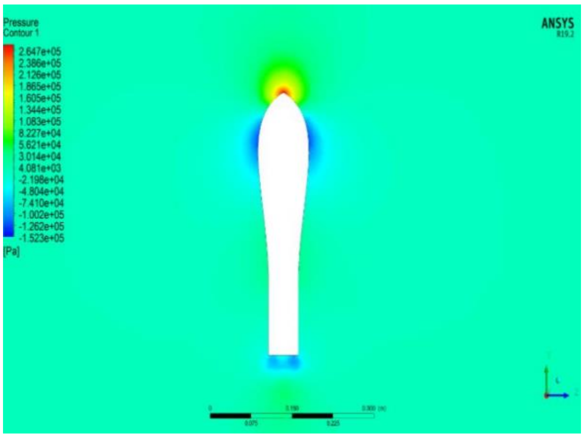


Figure 50: Velocity Effects

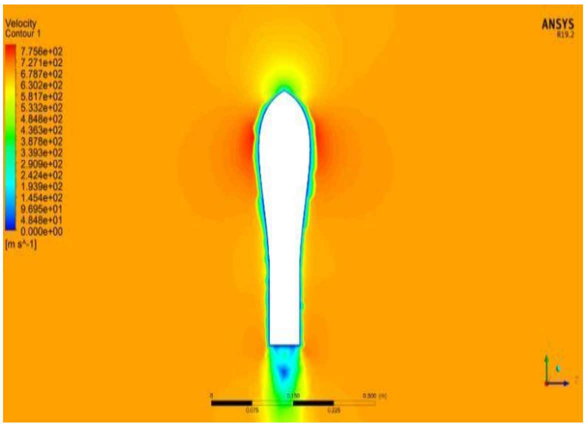


Figure 51: Coefficient of Drag vs Mach Number for Case 4

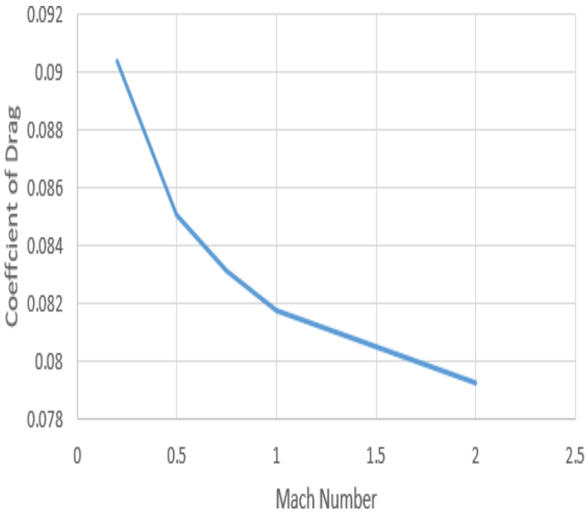
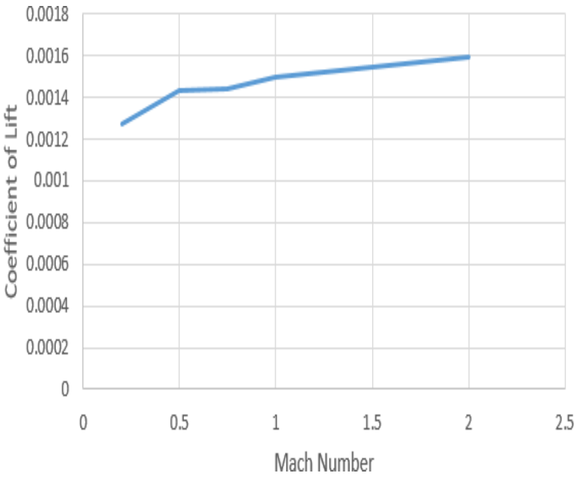


Figure 52: Coefficient of Lift vs Mach Number for Case 4



In case 4 missile system there is high pressure at the tip of the missile which is followed by a vacuum pressure is created at the curve which is at the short distance away from the tip and again vacuum pressure is being created at the tail of the missile, for boundary layer, there is a sudden decrease in the velocity at the tip which is followed by high velocity even more than free stream velocity for the total curved area, and at the tail again very low velocity profile is being developed or thick boundary layer is formed.

For Case 4 missile system coefficient of drag is inversely proportional to the Mach number in the early stage from 0.2 to 0.5 Mach number there is a sudden decrease in coefficient of drag and its decreasing rate is reduced continuously.

Coefficient of lift for Case 4 missile is increasing with reducing rate as for Mach number 1 to 2 there is very little change is observed.

Table 1: Coefficient of Drag for All Mach numbers

	Mach Number				
Case	**0.2**	**0.5**	**0.75**	**1**	**2**
-1	0.3468	0.3431008	0.3318876	0.3303848	0.3227552
-2	0.046602	0.044008	0.042367	0.042706	0.03938
-3	0.069586	0.066393	0.065363	0.064702	0.063243
-4	0.090396	0.085087	0.083129	0.081788	0.079249

Table 2: Coefficient of Lift for All Mach Numbers

	Mach Number				
Cases	**0.2**	**0.5**	**0.75**	**1**	**2**
1	-0.0020808	-0.00202011	-0.0020002846	-0.0017713388	-0.0010720455
2	0.0005499	0.000296	0.000317	0.000611	0.0003138
3	0.0026028	0.0028746	0.0029493	0.0029983	0.0030666
4	0.0012723	0.0014327	0.0014435	0.0015005	0.0015948

5.0 Conclusions

As the numerical study has demonstrated we are able to know about the drag coefficient acting on the different missile systems. Drag coefficient is depend on many factors such as roughness, variation in velocity and pressure of the fluid and flow separation. The effect of flow separation in the missile or any vehicle is play a great importance to the coefficient of drag, it increases the coefficient of drag to great extent and in this project we are simulating four types of missile using CFD simulation by ANSYS, for this simulation we should take equal free stream velocity, equal amount of volume and weight, identical material so roughness is being equal and identical atmospheric pressure (approximately).

Case 1 is very simple type of missile and in this missile very low vacuum pressure is developed as compared to the other types of missile systems whereas the flow separation is not being affect very much and finally due to low vacuum pressure there is very high drag coefficient. For Case 2 missile we create the front part of the missile to look like a Case 2 so that drag coefficient to be minimum for the foremost part but by using this theory the flow separation is affected the coefficient of drag, flow separation is occurred at rearward part of the Case 2 so, drag coefficient is increased but it is lesser than the Case 1 . For Case 3nd type of missile system the shape of the foremost part is may be considered as the mixture of both Case 2 and Case 1 , this type of missile is often used in the real life application in this type the coefficient of drag is minimum in the all four types of missiles, in this type there is very high vacuum pressure is being created at the most emerged part of the foremost portion in very small region and no flow separation is being observed or flow separation is being occurred insignificantly so, it is the most optimized design of the missile system it may be possible to decrease the coefficient of drag by making it Case 4 . For Case 4 type of missile system the figure of the foremost part is a little bit smaller than the Case 2 type missile and it is modified by designing it as a Case 4 so that no possibility of flow separation, in this system the high vacuum pressure is also generated at the most emerged part of the foremost portion, in this system coefficient of drag is very close to the drag coefficient of the Case 3nd missile but due to lower vacuum pressure than Case 3nd , the coefficient of drag of the Case 4 missile is being more (approximately) than the drag coefficient of Case 3nd system. But this system shows more continuous curve of drag coefficient vs Mach number. It is also used in small missile applications.

Now we concluded that Case 3 missile system having lowest drag coefficient. Case 4 system having little bit more drag coefficient than the Case 3 but in this system no flow separation is occurred so, it is being the best design to develop and most optimized design. Case 2 missile having coefficient of drag lesser than Case 1 system. Case 4 missile system is become the most optimized design in perspective of the flow separation and other factors of coefficient of drag, but we have not study the variation of the stresses developed in under the missile and some other factors. So, if you want to further study about these topics you can do it in future.

References

[1] S Piedra, F Martinez, CA Escalante-Velazquez, SMA Jimenez. Computational aerodynamics analysis of a light sport aircraft: compliance study for stall speed and longitudinal stability certification requirements. Aerospace Science and Technology. 2018, doi:10.1016/j.ast.2018.09.016

[2] F Rizzo, V D'Alessandro, S Montelpare, L Giammichele. Computational study of a bluff body aerodynamics: Impact of the laminar-to-turbulent transition modelling. International Journal of Mechanical Sciences, 178, 2020, 105- 620. doi:10.1016/j.ijmecsci.2020.105620

[3] J Sahu, KR Heavey. Parallel CFD computations of projectile aerodynamics with a flow control mechanism. Computers & Fluids, 88, 678–687. doi:10.1016/j.compfluid. 3(15), 2013.

[4] Y Zhou, L Hou, D Huang. The effects of Mach number on the flow separation control of airfoil with a small plate near the leading edge. Computers & Fluids, 156, 2017, 274–282.

[5] R Placek, P Ruchała. The flow separation development analysis in subsonic and transonic flow regime of the laminar airfoil. Transportation Research Procedia, 29, 2018, 323–329. doi:10.1016/j.trpro.2018.02.029

[6] P Razi, P Tazraei, S Girimaji. Partially-averaged Navier–Stokes (PANS) simulations of flow separation over smooth curved surfaces. International Journal of Heat and Fluid Flow, 66, 2017, 157–171. doi:10.1016/j.ijheatfluidflow.2017.05.005

[7] G Jones, M Santer, M Debiasi, G Papadakis. Control of flow separation around an airfoil at low Reynolds numbers using periodic surface morphing. Journal of Fluids and Structures, 76, 2018, 536–557. doi:10.1016/j.jfluidstructs. 2017.11.008

[8] KL Kang, KS Yeo. Combined effects of amplitude, frequency and bandwidth on wavepackets in laminar turbulent transition. Computers & Fluids, 197, 2020, 104-358. doi:10.1016/j.compfluid.2019.104358

[9] C Mills. High frequency pressure loss measurements of laminar- turbulent transitional flow. Flow Measurement and Instrumentation, 74,2020, 101-770. doi:10.1016/j.flowmeasinst.2020.101770

[10] W Chang, G Pu-zhen, W Zhan-wei, T Si-chao. Experimental study of transition from laminar to turbulent flow in vertical narrow channel. Annals of Nuclear Energy, 47, 2012, 85–90. doi:10.1016/j.anucene.2012.04.018

[11] SP Schneider. Hypersonic laminar–turbulent transition on circular cones and scramjet forebodies. Progress in Aerospace Sciences, 40(1-2), 2018, 1–50. doi:10.1016/j.paerosci.20 03.11.001