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Numerical Simulation of Magneto-Hydrodynamics Effect on Supersonic Flow of A Projectile

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Abstract

Plasma actuator is an active flow control tool, which has been evaluated by the aerodynamic researchers since last decade due to its simple structure, light weight, low energy consumption, and high time response. In this paper, the effects of plasma on aerodynamic behavior of a rocket at different flight conditions is numerically investigated. Results of plasma effects or variation of attack angle, Mach number, and flight altitude on the drag and lift coefficients are evaluated. Applying plasma increases the vertical velocity under the rocket canards which leads to higher pressures and therefore, higher pressure difference and forces are applied on the rocket canards which improves their functionality. Drag and lift coefficients are both increased due to the plasma, but the aerodynamic efficiency (lift to drag ratio) is increased by increasing potential difference. Outcomes shows that plasma effect is reduced with increasing of angle of attack and increased with the flight altitude and aerodynamic efficiency is changed between %3 and %60 by applying plasma.

Keywords: Plasma, Magneto Hydrodynamics, Flow Control, Performance improvement, Numerical Simulation.

1. Introlduction

The studies carried out in the past years are divided into three categories: the study of the physics of electric discharge of the actuator, the optimization of the plasma actuator and the applications of this device. Using the plasma actuator in the active control of the flow has been and will be of great interest to researchers; As an example, we can refer to the researches of Sato et al. [1], Zhang et al. [2], as well as Zheng [3], who used experimental tests to use the plasma actuator as a very practical tool in flow control. The conditions of using such operators are very effective on the flow distribution and control. In this regard, Mirzaei and Pasandideh Fard [4] investigated the difference between one-piece and three-piece plasma actuators on two different types of wings. They further admitted that the ability of the multi-piece actuator to improve the pressure distribution and postpone the lag angle is much higher than the one-piece one. In some past studies, such as the research of Mahboubidoost and Ramyar [5], the performance improvement rate of the target sample has been reported up to 40%. Shadaram et al [6, 7] studied the performance of a dielectric barrier discharge plasma actuator by both laboratory and numerical methods. Plasma actuators were tested for use in flow control on NLF0414 and NACA4412 airfoils, and the effect of different electrical modes on the pressure distribution around the airfoil, separation, velocity and turbulence characteristics in the near wake, as well as the frequency of vortices, were investigated. The results obtained from the numerical and laboratory modeling of the plasma actuator around the wing of NLF0414 show the improvement in the pressure distribution on the suction side, the reduction of the wake width and the ability of the actuator to control the vortex shedding frequency. It is worth mentioning that this operator has also been successful in the field of space propulsion and has been very effective in improving the performance of space missions and their acceleration. Jenmi et al [8], in 2008, published for the first time the idea of using plasma actuators to control a non-guided projectile at Mach 4, 5 and 6. In this research, they experimentally and numerically investigated a projectile model equipped with a plasma propulsion system in the impact tunnel. They also reported that the force produced by the plasma thruster is sufficient to change the trajectory of the projectile. In his subsequent research, Jenmi provided more research on the appropriate place to create plasma and also the power of plasma [9, 10].

Employing plasma actuator as an active flow control method due to its potential features has encouraged many researchers in this direction. So, in the present research, at the beginning of the task, the lift and drag coefficients of a canard-control projectile were calculated numerically in various flight conditions by means of Ansys-Fluent commercial software. Relevant analyzes were presented for Mach numbers 6, 6.5, 7 and angles of attack 5, 10 and 15 degrees. On the other hand, in order to approach the modeling of the projectile's flight envelope, various altitudes such as 50, 55 and 60 km were chosen to follow the simulations. Since, plasma operator is considered under the canard, changing the canard angle is also important. To investigate, two deviation angles of 0 and 20 degrees were considered for the canard and their effects were measured. Then, the desired analyzes were presented similarly on the ultrasonic projectile in the state where the plasma actuator was applied with different potential differences, and the results were compared with each other.

2. Numerical model

In order to simulate and validate, the results of NTCM missile simulation have been compared with the results of Ekgol's research [11]. Numerical analysis of NTCM missile at Mach number 1.75 and different attack angles has been done using Fluent software. On the other hand, to validate the MHD model, the results obtained from the present study have been compared with the numerical results of Thomas Kelsey [12], who applied the MHD model to the NACA 0012 wing. In the second part, the results of projectile simulation with canard are compared with experimental and numerical results. Fluent software is used for numerical modeling of the flow field around the NACA 0012 wing. In the presence of plasma, volume force effects are added to the Navier-Stokes equations by coding in the User Defined Functions (UDF) section of this software. The computational grid here is C-shaped, which is produced in ICEM CFD software.

3. Results

In general, the outcomes of the present article including two separated segments as follow;

3.1 The influence of plasma actuator on flow speed for canard at zero degree

In this section, the simulation results of the supersonic projectile at the zero-angle canard and at an altitude of 50 km and Mach 6 are presented. Figures 15 and 16 show the contours of the vertical velocity around the canards of the missile at an angle of attack of 5 degrees, without the presence of plasma, and with the application of 7 kV potential difference in the presence of plasma. By comparing these two figures, the effect of plasma can be obviously seen, which caused an increase in the vertical speed under the horizontal canards. Increasing the vertical speed under the canards will also increase the drag coefficient. In order to better understand the flow physics, streamlines and rotation distribution are presented in two figures (a and b) 17, respectively.

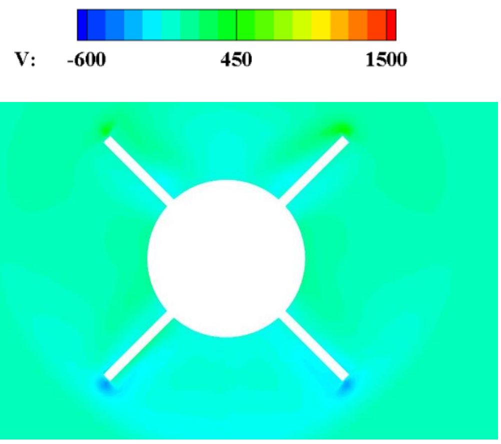


Figure 15- the vertical velocity contour around the canards of the missile at the angle of attack of 5 degrees without the presence of plasma (altitude 50 km and Mach 6)

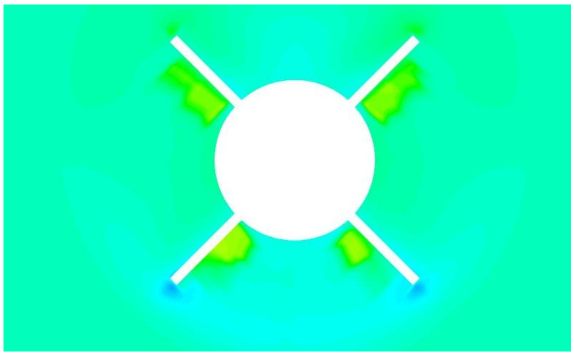
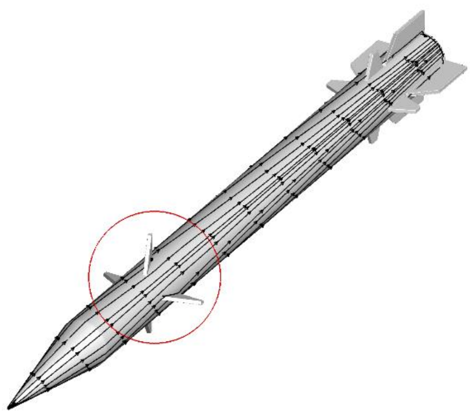


Figure 16- the vertical velocity contour around the canards of the missile at the attack angle of 5 with the application of 14 kV potential difference (altitude 50 km and Mach 6)

a



b

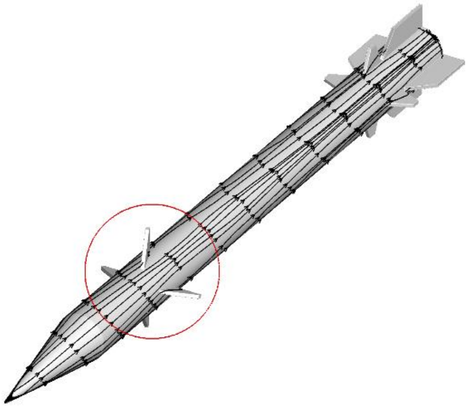


Figure 17- streamlines a) without and b) with the presence of plasma actuator, around the canards of the missile at the angle of attack 5 with the application of 14 kV potential difference (altitude 50 km and Mach 6(

3.2 Investigating the 20-degree deviation of the canards

In this part, the results related to the 20-degree deviation of the canards are discussed. In other words, the canards are deviated by 20 degrees, and on the other hand, the entire geometry rotates 45 degrees in the counter-rotating-clockwise direction around the missile axis. Ultimately, the geometry and canards of the missile will change in angle and shape according to Figure 19. From this section onwards, the results are presented under these conditions.

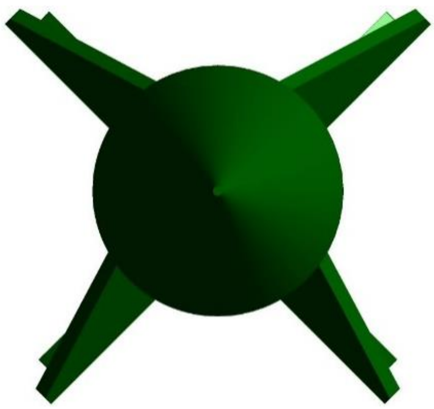


Figure 19- A view of the geometry of the rocket with a 20-degree angle of deviation of the canards

4. Conclusion

The lift and drag coefficients increase by increasing the applied potential difference under the canards. With the increase of the potential difference, the speed increases in the vertical direction, this increases the speed under the canards which will increase the pressure near and on the canards. Thus, this increases pressure that leads to increase the lift and drag coefficients. The lift and drag coefficients are both increased due to the effect of plasma, but the aerodynamic efficiency, $L/_D$, increases with the increase of the potential difference. In the same potential difference, with the increase of the angle of attack, the percentage of the aerodynamic efficiency (compared to the same angle of attack without applying plasma) decreases. Because by increasing the angle of attack, the speed increases in the vertical direction and the effect of the plasma momentum reduces.

At an altitude of 60 km and Mach 7, by applying a 10 kV potential difference under the canards at an angle of attack of 5 degrees, the aerodynamic efficiency has increased by nearly 66%. In the same flight conditions and by increasing the angle of attack to 10 and 15 degrees, the aerodynamic efficiency has been improved by 9 and 3 percent, respectively. With the change of flight conditions (increase in altitude and higher Mach), the aerodynamic efficiency under the influence of plasma has become many times higher than the previous state. Because as the flight height increases, the air density and pressure decreases. Therefore, with the same potential difference and volumetric force, the particles will have higher acceleration and speed. As a result, aerodynamic efficiency will increase by means of employing plasma.

A 20-degree deviation of the canards, similar to the results related to the normal state (0-degree deviation of the canards), the potential difference of the lift and drag coefficients increases. Increasing the canard deviation angle accelerates the flow separation and the drag force on the missile increases significantly. As a result, the aerodynamic efficiency decreases with the increase of canard deviation angle.

5. References

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