Investigation of the aerodynamic design effect on point mass flight parameters in hypersonic glider

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ABSTRACT

Hypersonic glide vehicles have been considered as untraceable systems with high maneuverability in recent years. On the other hand, flying in the range of maximum aerodynamic efficiency is important due to its effect on increasing range and improving air maneuverability. In this research, the hypersonic glider flight parameters including position and instantaneous velocity relative to the body profile and the amount of climb angle have been investigated using the point mass flight path determination method. The type of body profile has been selected due to the significant increase in aerodynamic efficiency and simplicity of redesign of other components, elliptic cross section. The study of aerodynamic coefficients in Mach 6.7 shows the high accuracy of the modified Newtonian method as the basis of calculations, which is then, corrected according to the flight conditions by the computational fluid dynamic. Due to the instantaneous changes in aerodynamic coefficients at each time step, depending on the altitude and Mach number, a two-way coupling between aerodynamic analysis and point mass flight is used. The results show a 54% increase in range and a 29% increase in incident speed with a decrease in body height. These values are 16% and 74% in the studies related to the radius of nose curvature and 44%, 25% in the study of the initial climb angle

KEYWORDS

Hypersonic glider, Hypersonic aerodynamic, Flight parameters, Point mass flight path.

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1. Introduction

The design and analysis of aerodynamic shapes of hypersonic gliders is done according to the flight path and flight parameters. The range of speed, altitude and time are among the determining parameters in the type of analysis and design of this type of gliders. By determining the movement parameters and creating constraints, the path and flight conditions of the glider [1] are determined. Then the aerodynamic profile can be obtained by observing the design principles in other conditions. A comparison between hypersonic glider paths compared to other systems can provide a better understanding of its benefits. Due to the curved path in ballistic projectiles, it is easier to predict its motion. In contrast, hypersonic gliders have a variety of maneuvers due to their high velocity in concentrated flight conditions [2]. In addition to creating flight variety, these maneuvers are effective in using constraints to determine the path. To design a suitable aerodynamic shape, it is necessary to check the path and related parameters such as the speed of the glider during the movement. Dynamic equations of point-flight mass [3] investigate flight path and motion parameters using ascending and descending forces. As a result, the calculation of up and down force is considered as important parameters for aerodynamic design.

In this study, rapid aerodynamic analysis methods have been investigated to determine the initial lift and drag forces. Then, some of the parameters of body cross-section compression, nose curvature and initial climb angle due to their high impact have been investigated for kinetic study with aerodynamic coefficients corrected from CFD. In the simulation of glider movement, the equations governing the flight of point mass have been used by considering the changes of density and air temperature with respect to altitude.

2. Methodology

To select the basis aerodynamic analysis method, first a comparison between the accuracy of the two modified Newtonian methods "MDMN" and the second-order shock-expansion method "MDSE" using the missile Datacom code. The study performed in this section is related to Mach number 6.77 according to the results of Neal laboratory [4] in Figure 1 for this purpose, two common types of sharp and blunt bodies have been selected due to the difference in the flow pattern for the shock wave generated in the hypersonic flow. Check the results of modified Newtonian and shock-expansion methods in each body compared to the experimental and numerical results shows the higher accuracy of the modified Newtonian method than the shock-expansion method. As a result, the extraction of base aerodynamic coefficients has been performed by the modified Newtonian method. Computational fluid dynamics solution has been used to correct the aerodynamic coefficients and increase the accuracy of the results (Figure 2 and Figure3).

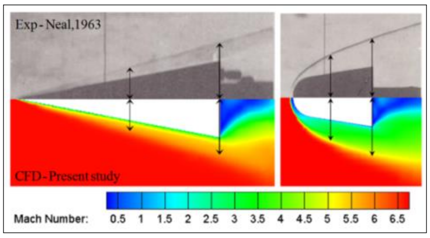

Figure 1. Comparison of flow pattern in numerical analysis of the present study compared to the experiment of wind tunnel by Neal [4]

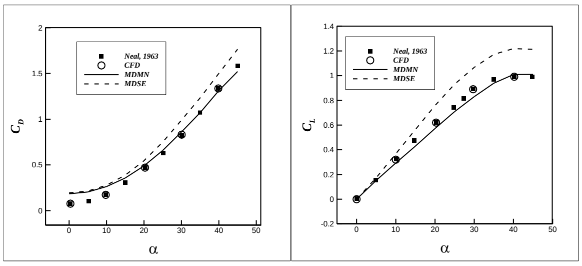

Figure 2. Comparison of aerodynamic coefficients in sharp geometry using numerical and analytical methods of the present study in relation to Neal experimental results [4]

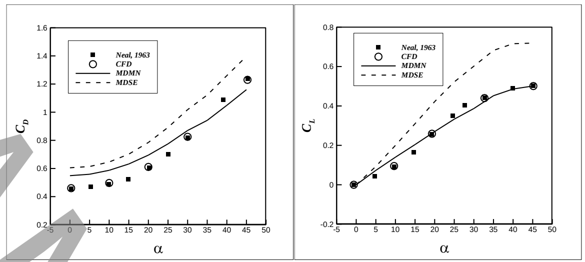

Figure 3. Comparison of aerodynamic coefficients in blunt geometry using numerical and analytical methods of the present study in relation to Neal experimental results [4]

In non-equilibrium flight conditions, the sum of the effects of aerodynamic forces, including the up and down force on the air conditioner and its weight force, determines the direction of movement of the air conditioner. In this section, the study of the three-dimensional flight path [5] of the airflow is determined as a point mass according to the positioning angle, velocity and altitude of the moment. Given the elliptical shape of the earth and its rotational motion, the three-dimensional path of the point mass of an incoming glider, as shown in Figure 4, can be represented as relations (1) to (4). In these relations, it represents the radial distance of the glider from the center of the earth, it represents the latitude, it represents the speed of the glider relative to the ground, it represents the angle of the flight path and it represents the angle of progress. The forward angle from the north is measured in a clockwise direction. They also represent the angle of lateral deviation with respect to the path of the glider and the rotational speed of the earth, respectively.

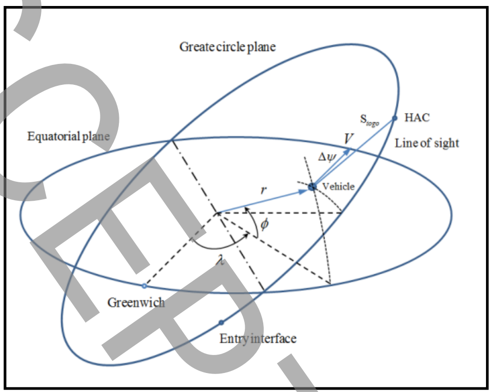

Figure 4. Schematic view of the glider's motion parameters in point mass flight [5]

$$\frac{dr}{dt}=V\sin\gamma,\ \frac{d\lambda}{dt}=\frac{V\cos\gamma\sin\psi}{r\cos\phi},\qquad\frac{d\phi}{dt}=\frac{V\cos\gamma\cos\psi}{r} \tag{1}$$

$$\frac{dv}{dt}=-\frac{C_D\rho V^2 S_r}{2m}+g_r'\sin\gamma+g_{we}(\cos\psi\cos\gamma\cos\phi+\sin\gamma\sin\phi)-\omega_e^2 r(\cos\phi\sin\phi\cos\psi\cos\gamma-\cos^2\phi\sin\gamma) \tag{2}$$

$$\frac{d\gamma}{dt}=\frac{C_L\rho VS_r}{2m}\cos\sigma+g_r'\frac{\cos\gamma}{V}+g_{we}\frac{(-\cos\phi\cos\psi\sin\gamma+\sin\phi\cos\gamma)}{V}+\frac{\omega_e^2 r}{v}(\cos\phi\sin\phi\cos\psi\sin\gamma+\cos^2\phi\cos\gamma)-2\omega_e\cos\phi\sin\psi+\frac{V\cos\gamma}{r} \tag{3}$$

$$\frac{d\psi}{dt}=-\frac{C_L\rho VS_r}{2m\cos\gamma}\sin\sigma-g_{we}\frac{\cos\phi\sin\psi}{V\cos\gamma}+\omega_e^2 r\frac{\cos\phi\sin\phi\sin\psi}{V\cos\gamma}+\frac{Vtg\phi\cos^2\gamma\sin\psi}{r\cos\gamma}+\frac{2\omega_e}{\cos\gamma}(\cos\phi\cos\psi\sin\gamma-\sin\phi\cos\gamma) \tag{4}$$

3. Results and Discussion

Assuming the value of negative initial climb angle of 5 degrees and the amount of nose curvature equal to 8 cm, the amount of compression ratio of the body section in conditions equal to 0.4, 0.6, 0.8 and 0.95 has been investigated. The results show an increase of 1700 km in flight range equivalent to 54% compared to the maximum flight range. In addition, the amount of flight time and the speed of dealing with changes in the compression of the fuselage have changed by 50 and 29%, respectively, in different ratios. The frequency of height recovery in these conditions is set to at least one state and a maximum of three states. Figure 5 shows the aerodynamic parameters including nose curvature and body compression ratio as well as the initial climb angle at altitude changes relative to the flight path.

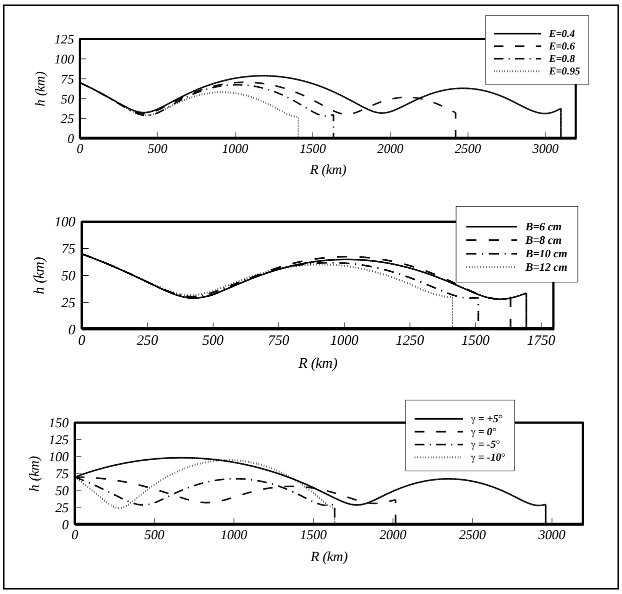

Figure 5. Discussion of parameters in altitude changes with respect to the flight path

4. Conclusion

The study of the aerodynamic shapes effect on hypersonic glider flight parameters shows the high impact of aerodynamic design. As a result, due to the high importance of aerodynamic design, this step is used as a design reference considering other constraints. In addition, the constraints at the beginning of glider release can greatly affect the flight pattern that must be considered.

5. References

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