Numerical study of aero-optical effects at transonic regime around the Tomahawk cruise missile optical system

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Abstract—Due to the presence of temperature and density gradients in the flow field and the formation of turbulent and large vortices during the passage of the flow around the optical system in autonomous vehicles, causes light refraction, leading to insufficient accuracy in positioning, trajectory deviation in projectiles and errors in imaging systems. In this research, by using the Gladstone-Dale equation, the refractive index field can be extracted from the density field. Then, with the density field that obtained from numerical solution, ray tracing equation is solved using the 4th-order Runge-Kutta method, and the amount of light deviation is extracted. The results show that the aero-optic phenomenon is affected by the turbulence of the flow and the boundary layer, which plays an essential role in optical deviations in the flow field with variable density

Keyword: Aero-Optics, Refractive index, Ray Tracing, Light Refraction

1. INTRODUCTION

In recent years, researchers have been conducted in the field of investigating optical aberrations under different conditions. In a numerical study, the evaluation of optical aberrations around a spherical enclosure affected by the aero-optic effect was investigated by Hui et al. The results indicate a significant increase in optical aberrations in flows with a Mach number greater than 2 [1].

Yu et al. conducted research on the optical aberrations around the spherical chamber. The results showed that the non-uniform distribution of the refractive index is the cause of optical aberrations [2]. Jiang et al. studied the effect of aero-optics on air-optical imaging of a surface-to-air missile. The distribution of the density field around the optical system was analysed and the refractive index field was calculated. The results showed that with the increase in height, the refractive index gradually decrease [3]. Guo and Liu presented a method to predict the deviations of light passing through the aero-optic field caused by a supersonic mixing layer. The results obtained with the help of this model are in good agreement with the experimental data [4].

2. METHODOLOGY

1. GOVENING EQUATION

The governing equations in this research include the laws of conservation of mass, momentum and energy.

2. RAY TRACING METHOD

Ray tracing was done by using the refractive index field based on the obtained density field, then the light deviation was extracted based on the ray equation (1).

$$\frac{d}{ds}\left(n(r).\frac{dr}{ds}\right) = \nabla n(r) \qquad (1)$$

In equation (1), r represents the position vector of the unit ray path. n(r) is the refractive index at the location of the ray and ds is the path length. ∇n(r) is the slope of the refractive index at the beam location r and dr/ds represents the unit vector in the tangential direction along the propagation path.

3. GEOMETRY MODELLING

The geometry of the Tomahawk missile is shown in the figure 1.

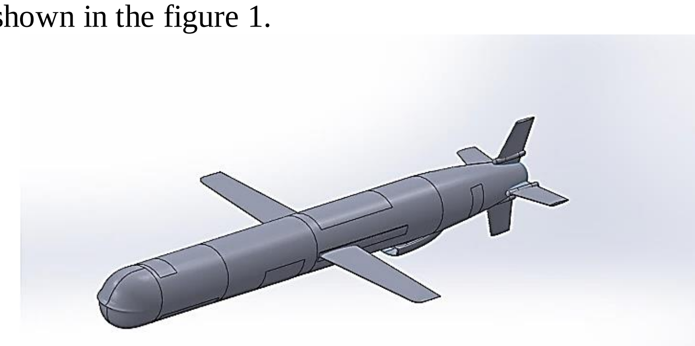

Fig. 1 The designed geometry of the Tomahawk cruise missile

3. RESULTS & DISCUSSION

The results show the optical deviations around the optical system of the missile that flight at the Mach number of 0.8.

In order to validate the simulation, a validation of the pressure distribution around an airfoil at the transonic flow regime was performed and compared with experimental data [5]. Figure 2 show the Mach number contour around the missile. Acceleration of the flow on the front surface of the missile has caused an increase in the local Mach number, pressure drop, decrease in density and the occurrence of a shock wave (Mach wave). All of the mentioned cases will lead to a strong gradient of the density field and as a result, high optical deviations.

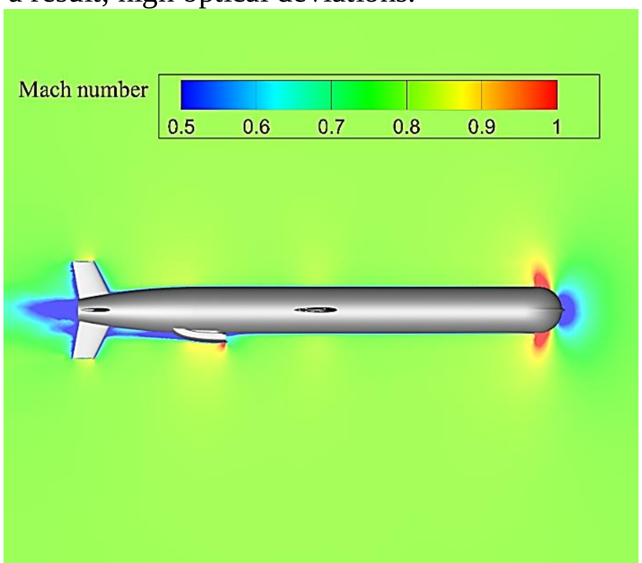

Fig. 2 Contour of Mach number of the flow around the Tomahawk cruise missile

The changes in light refraction implies that the light refraction increases with the increase of the viewing angle of the camera. In order to describe this behaviour, the density contour around the nose of the missile is shown in Figure 3.

CONCLUSION

This research was investigated and discussed the aero-optical effect of the cruise missile optical system. The deviation of the object's position decreases with the increase of the camera's viewing angle, which indicates an inverse trend with the amount of light refraction angle.

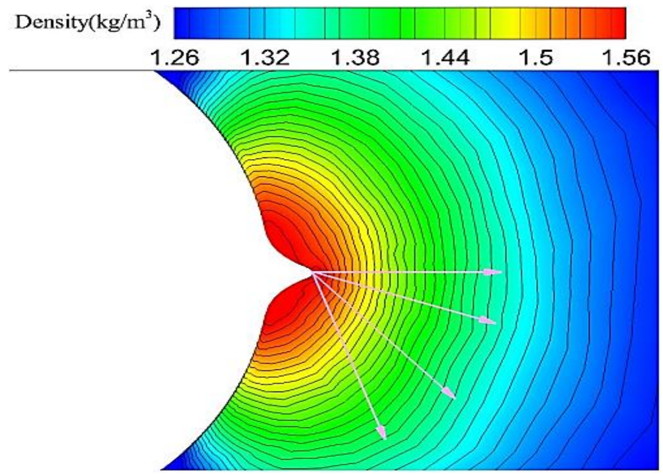

Fig. 3. contour of the density of flow field in the areas near the nose of the cruise missile

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