Effect of Leading Edge Porosity on the Flow Field of an Air Launched Grenade

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Abstract
Reported are the results of experiments on flow field of a forward facing cavity formed by a shaped-charge of a ribbon-stabilized air-dispensed grenade (Fig. 1) with different porosity openings in the front lip of the cavity. Previous research of flow visualization of the cavity without any porosity revealed the presence of a detached primary singular point outside the cavity and secondary flow inside with periodic ejections that interacted with the wake as low frequency oscillations. The present investigation was conducted in the Auburn University 18 in x 18 in water tunnel. Flow visualization consisted of hydrogen bubbles and laser induced fluorescence of fluorescent dye. By providing relief to the flow the primary singular point moved inside the cavity thus reducing the unsteadiness. Preliminary results indicate that large scale disturbances were attenuated due to porosity and that the wake flow interactions were reduced. Final paper will include results and conclusion of the ongoing work.

Nomenclature

\( U_\infty \) : Free stream velocity

\( x, y, z \) : Right hand coordinate system with origin at the center of the cavity lip

Introduction

The air-dispensed grenades sub-munitions are ribbon stabilized and are designed to descend vertically and impact the target at low angles of attack at a terminal velocity with minimum oscillations (Fig. 1)
Figure 1. Ribbon stabilized air launched grenade

Air-launched grenades are short aspect ratio bluff bodies with a well defined singular point (stagnation point) that is detached and lies at a certain distance ahead of the body during descent. Because of the geometry of the shaped-charge, a grenade acts like a forward facing cavity with some exchange of fluid between the cavity and the surrounding.

Uniqueness of the primary singular point and downstream effects have been documented (Rifki et al. 2006). Effects of introduced porosity however have not been documented. The purpose of the present investigation was to understand the effects of varying porosity near the forward lip of the cavity on the mechanism of fluid dynamic interactions between the singular point, flow inside of the cavity, and the wake of a short non-streamlined body with abrupt leading and trailing edges such as the air-launched grenade.

2 Experimental setup

A full scale grenade model with shaped-charge cavity configuration and porosity openings with diameters ranging from .165 mm to .33 mm at angles from 20 to 40 degrees was used in this investigation along with a model with no openings. Model was manufactured from a clear acrylic stock and was polished until transparent for flow visualization. Side and front view of the model are shown in Fig. 2. Additional details can be found elsewhere (Auman and Dahlke 2000).
2.1 Flow visualization

A hydrogen bubble probe with a single platinum wire was used for flow visualizations. Bubble probes were mounted on a separate two degrees of freedom traversing system for precise positioning. The quantity and size of the bubbles was controlled by a set of variable voltage power supplies (15 – 40 volts.) The centerline planes of the models were illuminated with the help of OZ Optics laser light sheet generator attached to a 5W Argon-Ion laser. Fluorescent dye was also injected inside the cavity to examine internal flow structures. A Sony CCD camera was used to capture images that were recorded in real time. Flow visualization tests were conducted in the Auburn University 45 cm x 45 cm cross-section water tunnel. Water tunnel has a maximum velocity of 1 m/s and is equipped with additional top walls for open or closed surface operations. Reynolds numbers based on diameter of the cavity ranged from 4000 to 8000. Model was mounted from the rear on a straight tube connected to C-Strut that rested on top of the tunnel sidewalls. The support tube was also used for injection of fluorescent dye for flow visualization inside the cavity. Details of the model support system are shown in Fig. 3.
Figure 3. Water tunnel model support system

2.2 Drag Measurement

Drag data was taken at an angle of attack of zero degrees at a Reynolds number of 58000. Drag tests were conducted in Auburn University 120 cm x 91 cm cross-section closed-circuit wind tunnel. Model was mounted from the rear on a sting attached to shrouded force balance. Details of the model support system are shown in Fig. 4.

Figure 4. Wind tunnel model support system
3 Results and Discussion

A flow visualization image of a model with porosity is shown in Fig. 5 and an image of a model without porosity is shown in Fig. 6. The free-stream is marked with a vertical sheet of hydrogen bubbles from a platinum wire and the flow inside the cavity is visualized with the help of fluorescent dye injected directly in the cavity. One can see the flow visualizations of each model in Figs. 8-16. Analysis of video records of flow visualization revealed that both increasing the angle and diameter of the opening with respect to the horizontal and moves primary singularity point further into the cavity by providing relief to the flow. The primary singularity point being further into the cavity causes less unsteadiness and delayed separation. Drag results revealed that the drag of the models with porosity increased compared to non-porous at all angles except 30 degrees. Therefore models with porosity at 30 degrees had less drag than a non-porous model.

![Figure 5](image)

**Figure 5.** Flow visualization of the shaped-charge porous cavity (flow from right to left)

Diameter = 1.65 at 30 degrees
Figure 6. Flow visualization of the shaped-charge non-porous cavity (flow from right to left)

Figure 7. % Increase in Drag of Porous Grenade-Bodies @ Re = 58000
4 Conclusions

Comparison of flow visualization of grenade-bodies with openings in the front of the leading edge to grenade-bodies without porosity shows that the singular point moves inside of the cavity and the separation point from the downstream surface of the grenade-body is delayed. Grenade-bodies with the largest openings and with largest angles from the horizontal reduced the unsteadiness and wake flow interactions the most. Flow inside of the cavity is made of structures that contain outside flow and oscillates at low frequency ejecting from the cavity. After leaving the cavity, these structures reside in the reattachment region before leaving the wake.

Appendices

Appendix 1: Porosity Information

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Appendix 2: Flow visualizations of each model

**Figure 8.** Flow visualization of Model 1

**Figure 9.** Flow visualization of Model 2
Figure 10. Flow visualization of Model 3

Figure 11. Flow visualization of Model 4

Figure 12. Flow visualization of Model 5

Figure 13. Flow visualization of Model 6

Figure 14. Flow visualization of Model 7

Figure 15. Flow visualization of Model 8
Figure 16. Flow visualization of Model 9

References